SUMMARY OF THE DEVELOPMENT OF THE SPECIALIZED QUADRUPOLE MASS SPECTROMETER - PHASE V

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16. Abstract

The development (Phase V) of the Specialized Quadrupole Mass Spectrometer has resulted in a greatly improved system, which has been shown to give performance increases in both the resolving power and dynamic range of the mass spectrometer. Resolving powers of up to $m/\Delta m = 90$ have been obtained while maintaining 100 percent transmission through the mass filter (for flat-topped peaks). With pointed peaks, resolving powers of up to $m/\Delta m = 900$ have been demonstrated. The dynamic range of the systems have been increased to greater than 10^6. Mechanical isolation of the mass spectrometer from the vacuum envelope has also been performed to reduce stresses on the system imposed by either the envelope construction or by external environmental conditions.

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TABLE OF CONTENTS

LIST OF ILLUSTRATIONS

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SPECIALIZED QUADRUPOLE MASS SPECTROMETER (PHASE V)

INTRODUCTION

Since 1963, the development of Specialized Quadrupole Mass Spectrometers has been performed by Perkin-Elmer Aerospace Division (ASD) for the National Aeronautics and Space Administration at Goddard Space Flight Center. This development has been performed to obtain small systems for the analysis of the constituents of the earth's and other planetary atmospheres. This development program has been documented in the final reports prepared for Contracts NAS5-3453[1] and NAS5-11045[2]. Applications of the instruments developed have been utilized in earth-orbital satellites, e.g., the OGO-F Satellite Program, and in sub-orbital sounding rockets launched by Goddard Space Flight Center (GSFC). This report covers the development effort (Phase V) since the conclusion of Contract NAS5-11045 and describes the design improvement of the quadrupole mass spectrometer to provide increased analytical capability and performance of the system. The performance obtained from the systems fabricated showed a marked improvement in the sensitivity, resolving power and dynamic range over that of the previously produced designs.

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1. The Perkin-Elmer Corporation, Aerospace Division, Summary of the Development of the Specialized Mass Spectrometer and Study Reports, Final Report prepared under Contract NAS5-3453, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

2. The Perkin-Elmer Corporation, Aerospace Division, Summary of the Development of the Specialized Quadrupole Mass Spectrometer - Phase IV, Final Report prepared under Contract NAS5-11045, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

OBJECTIVES

The initial contract, NAS5-11185 as defined by the Statement of Work, was for four cylindrical rod quadrupole mass spectrometers reflecting the integration of specialized instrumentation developed and produced under Contract NAS5-11045 and NAS5-3453. During March of 1969 the contract was modified to reduce the quantity from four cylindrical rod systems to three hyperbolic rod systems with extensive modification in the design.

The contract was further amended to incorporate four design studies, which are listed below:

a. Quadrupole Optimization Study - dealing with the theoretical optimization of the ion source and quadrupole analyzer design upon specification of system requirements.

b. Quadrupole Ion Entrance Mask Study - Studying the increase in quadrupole resolving power which can be gained by mechanically eliminating a large portion of the ions that cause mass peak tails.

c. Quadrupole Segmented Rod Study - Analysis of the potential improvement in quadrupole performance which can be gained with the use of segmented quadrupole rods and delayed dc rod biasing.

d. Inlet Sampling Tube Study - study of the design requirements for gas sampling inlet lines for quadrupole mass spectrometer systems encased within atmospheric reentry vehicles.

The final reports for the above four studies were submitted under separate covers on Contract NAS5-11185.

The contract was later amended to include the design, fabrication and test of an open ion source similar to those used in the Rocket Quadrupole Mass Spectrometers, under Contract NAS5-3144[3]. This effort consisted of miniaturizing the open ion source to make it compatible with the Specialized Quadrupole Mass Spectrometers, while retaining the object-imaging focusing system for the acceptance of energetic and angular molecules.

3. The Perkin-Elmer Corporation, Aerospace Division, Ion Focusing Study, Final report prepared under Contract NAS5-3144, National Aeronautics and Space Administration, Goddard Space Flight Center, Greenbelt, Maryland.

The final modification to the contract was to perform the design activity and produce fabrication drawings for an advanced Specialized Quadrupole Mass Spectrometer utilizing four inch quadrupole rods with reduced rod spacing.

DESIGN

The Quadrupole Mass Spectrometer developed under Contract NAS5-11045 indicated that a substantial improvement in performance characteristics could be obtained utilizing extremely precise quadrupole rod alignment and hyperbolic quadrupole rods. Following this program further performance improvement and reliability of the design was felt possible by considerations of the following:

a. Quadrupole Ion Entrance Masking. The mechanical elimination of unstable ions entering the quadrupole which have initial conditions that do not allow them to be rejected by the quadrupole mass filter, because the length of the rods is terminated to a finite value. These unstable ions cause the large tails on the sides of the mass peaks in conventional quadrupole designs. The crosstalk of two adjacent masses, at a given resolution, will thus be improved significantly by reducing the magnitude of these tails.

b. Mechanical Isolation and Ease of Assembly. The mounting of the ion source, quadrupole rods and electron multiplier was felt to be a self-contained structurally solid system and, thus, should be isolated from the vacuum envelope (housing) in order to reduce stresses on the system by both environmental and tolerance conditions of the vacuum envelope. Also, packaging advantages could be obtained by having all electrical feedthroughs located on one side of the system, and, furthermore, by utilizing a baseplate approach, all mountings and feedthroughs could be located on a flat surface. The vacuum envelope would then be a simple cover, allowing the testing and tuneup to be performed in a nude configuration, after which the cover could be welded to the baseplate. This approach should reduce the cost of the housing by eliminating costly machining operations. Another advantage of the baseplate approach is that the system could be easily assembled and worked on, since the majority of the parts would be accessible in the final assembly form.

c. Elimination of Neutral Background Level. Because of the axial nature of the quadrupole mass spectrometer, ions formed in the ion source can undergo charge exchange with neutral molecules, leaving neutralized molecules which have a velocity vector down the axis of the ion source and quadrupole. These neutrals, formed in the ion source, are unaffected by the electric fields of the quadrupole mass filter and continue to the detector of the system. When an electron multiplier is used as the detector, these neutrals generate secondary electrons at the first dynode of the multiplier, causing a constant background level as the mass range of the system is swept over. The intensity of this level is a function only of the total pressure within the ion source.

Two means were considered to reduce this phenomena. The first, as proposed by the University of Michigan, was to simply offset the electron multiplier and utilize its leakage field to bend the ions into its entrance aperture. The second, was to offset the multiplier and build a deflector mechanism to focus the ions exiting the quadrupole into the entrance aperture of the multiplier.

Ion Entrance Masking

The design of a mask to effectively reduce the magnitude of peak tails was undertaken in a separate study program, as previously explained. However, in order to justify this study program the Phase IV B quadrupole system manufactured under Contract NAS5-11045, was provided with masks of various sizes at the ion entrance aperture (ion source nozzle). The data obtained from this instrument showed a marked reduction in peak tails could be obtained with a relatively small loss in sensitivity (due to the area reduction of the entrance aperture). These data proved that the masking theory was sound, and thus, the study program was pursued to obtain the information necessary to optimize the design of a mask.

The study of the ion entrance aperture mask included extensive computer acquired data with results showing that masking the ions entering the quadrupole very near the X and Y axes does indeed improve the resolution of the system.

The resolution of the quadrupole is largely limited by the tails on either side of the peak. These tails are caused by ions which are theoretically unstable, but possess a small amplitude at the end of a finite length quadrupole. Other parameters, such as res lution, phase of entry and initial angle and amplitude also play a large role in determining the amplitude or size of the tails.

As shown in the mask study, the most penetrating unstable ions are those with small initial amplitude and angle. This is true for all phases of entry. There are conditions where a large initial amplitude and large initial angle can make an ion very penetrating for a given quadrupole length, but this is generally restricted to a few entrance phase angles. The conclusion derived from the theoretical and computer analyses is, that elimination of ions with small initial amplitude improves the performance of a quadrupole mass spectrometer. This elimination is accomplished by a cross grid at the exit side of the nozzle.

A tradeoff of improved data quality versus sensitivity occurs, however, when partial elimination of ions occur. In the actual quadrupole system delivered the optimum theoretical tradeoff conditions were obtained when 0.003 by 0.002 inch wires were crossed over the nozzle opening of 0.010 inch diameter.

Mechanical Isolation and Mounting Design

The mechanical design requirements, imposed by the necessity of a mechanically isolated mass spectrometer assembly (ion source, quadrupole mass filter, and electron multiplier) within a vacuum housing, basically implies that single point mounting of the assembly to the housing be utilized. This would thus prevent external stresses (from the housing or the external environment) from causing any distortions or mechanical shifting in the parts of the mass spectrometer components. This approach is not compatible with the mass spectrometer requirements, however, since a number of connections to the housing are necessary, e.g., electrical wiring of electrodes to vacuum feedthroughs and sample inlet tubulation.

As a compromise three flexure joints were utilized to join the mass spectrometer assembly to the housing. These flexure joints allow relative freedom of movement in two axes, but restricted motion in the third axis, at a single point.

Two flexure plates were used, one at each end of the quadrupole rod assembly. These plates provided damped flexibility as the lateral axes of the rod assembly and relatively large freedom of movement in the axial direction. The axial flexibility was then restricted at a single point by the use of a rod assembly which was rigid in the axial direction, but was flexible in the lateral axes. The flexure plates are shown in Figure 1, and the axial rod assembly is shown in Figure 2.

The hyperbolic quadrupole rod assembly was redesigned from the Phase IV B configuration, in order to insure alignment of the rods rather than allowing for adjustment during assembly to provide the required alignment. The second goal of this redesign was to decrease the weight of the quadrupole rods, since the Phase IV B rod assembly was not engineered to minimize weight, but rather to obtain stability for the rod alignment. The new design consisted of bored out monel rods upon which the hyperbolic surface was ground. At each end of the rod, two flat flange surfaces were ground, spaced ninety degrees from each other. The resultant rod is shown in Figure 3. A precision ground ceramic spacer was placed between the flat flanges of the adjacent rods. Each of the four flat ceramic spacers were located with respect to each other by designing them onto a flat ceramic plate, which in turn was mounted to the flexure plates at each end of the rod assembly. The ceramic plate at the ion source end of the rod assembly also provided the alignment criteria for the ion source nozzle. This was accomplished by locating a precision hole in the ceramic, through which the nozzle was inserted, using dowel pin locating clearances between the nozzle and the ceramic. The exiting ions are transmitted to the electron multiplier through a large centered hole located in the ceramic at the ion exit end of the rod assembly. The ceramic plate, with the rod spacing tabs, used at the end of the rods is shown in Figure 4.

A structural analysis of the rod assembly, flexure plates and ceramic plates was performed and the results of this analysis is presented in Appendix A.

The sample inlet connection between the ion source and the housing was designed to incorporate a bellows. This was done in order to maintain mechanical isolation for the sample inlet tubulation connections. A photograph of this connection and the ion source is shown in Figure 5.

Elimination of Neutral Background Level

While the two methods mentioned earlier were considered for elimination of the neutral background level, a variation of the second proposed method was utilized. This method involved using the electron multiplier as both the deflector and as a detector. By sacrificing the use of one stage of the multiplier gain, the first dynode could be utilized as an ion deflector and still effectively reduce the neutral level. A second aperture could then be placed between the deflector lens (first dynode) and the first secondary electron emitting stage (second dynode), such that the lens geometry in front of the electron multiplier would remain the same.

Conversations with ITT Electron Tube Division, the multiplier supplier, indicated that this approach could be incorporated into the previously used F4020 AM multiplier. A geometry for this front end of the multiplier was chosen and evaluated by ion trajectory plotting using a digital computer. A plot of a number of trajectories is shown in Figure 6. These results showed that the deflector-multiplier method could be utilized effectively.

By incorporating the ion deflector into the electron multiplier assembly, an advantage was gained in the design and fabrication of the vacuum envelope. The envelope could thus be built in a single straight section, rather than having to include a multiplier housing mounted at ninety degrees to the analyzer housing. The electron multiplier was designed to be supported by a bracket, which in turn mounted to the flexure plate at the ion exit end of the quadrupole rod assembly.

A photograph of the mass spectrometer assembly is shown in Figure 7. This photograph shows the flat plate mounting surface in which all of the electrical feedthroughs are located. The electron multiplier and its mounting bracket are also clearly shown in this photograph. The vacuum envelope then consisted of a simple cover which mounted over the assembly and was electron beam welded around the edges to seal the seams.

Open Ion Source Design

A miniaturized version of the open ion source developed under Contract NAS5-3144 was designed to be compatible with the smaller quadrupole systems developed for the analysis of planetary atmospheres. This effort consisted of scaling down the dimensions and focusing properties of the earlier ion source. The resultant design was then tested with one of the current developed systems.

Advanced Quadrupole Mass Spectrometer Design

The design work for a further miniaturization of the Specialized Quadrupole Mass Spectrometer was performed based upon the results of the optimization study generated on this contract. The final design of the four inch quadrupole system has a smaller block dual filament ion source with the inlet through one of the anodes. A chamber was also designed as part of the inlet system to thermalize the molecules by wall collisions. The dual filament ion source, in addition to the changes mentioned above, was redesigned so that its conductance was decreased from approximately fifty to about fifteen cubic centimeters per second. The hyperbolic rods, along with the decrease in length from six inches to four inches, had the quadrupole rod spacing parameter, r_0, decreased from 0.200 to 0.100 inch.

The multiplier geometry is also decreased such that the entire system, except for the thermalizing chamber, fits inside a cylindrical housing of about 1.75 inches outside diameter by about ten inches long. All the electrical connections are routed through feedthroughs on either end of the cylinder. The multiplier is a deflector type, as described above, with of course, a smaller geometry. A further miniaturization of the open ion source was also performed to obtain compatibility with the smaller geometry requirements. The fabrication and performance results of these instruments will be reported in Phase VI of the development program, now being performed under Contract NAS5-11308.

CHRONOLOGICAL EVENTS AND TEST RESULTS

Studies on the Phase IV B Analyzer

The dual filament ion source was installed in the Phase IV B quadrupole analyzer on 9 June 1969. Considerable effort was expended to optimize the operation of the dual filament ion source. This effort was directed towards obtaining a set of operational curves with varying conditions so that the optimal operating parameters could be determined. Some of these operational curves are shown in Figures 8 through 10. The best data was obtained with reduced ion energy and ion energy spread, as shown in Figure 11, however there was a considerable sacrifice of intensity to obtain the data shown in this figure. At this time, the Aperture Mask Study was just beginning and the decision was made to try a Y-axis mask by placing a 0.001 inch wire in the appropriate orientation at the nozzle. Several scans were made, but there was no appreciable change of the peak shape except for the reduction of the intensity because of the wire masking some of the ions.

The rod polarity was reversed to determine the effect in the X-axis, but again there was no appreciable change in data. The reason for the lack of improvement became obvious after the mask study was completed, but at the early stages of the investigation there were no guide rules to follow to indicate the size and effect of the mask. Later, when the masking effect was better understood it was calculated that a 0.001 inch wire would only reduce the tails by less than ten percent of their initial value. This is a reduction which could easily go unnoticed with all the other variations that can occur.

As mentioned above, having no guide rules to go by at that time, it was decided to try an upper limit of wire size to make the effect very apparent.

The size of the upper limit was partially determined by the amount of intensity loss which was to be sustained. The wire size was determined to be 0.005 inch. The wire was spot welded onto the nozzle and a scan was run. Figure 12 shows this scan, which obviates the tail reduction when compared with a similar scan (Figure 13) without any mask. The rod polarity was again reversed to determine the tail reduction in the X-axis and again a dramatic decrease appeared, as shown in Figure 14.

A wire size mask of 0.005 inch with 0.010 inch diameter nozzle, however, would eliminate most of the intensity; thus, the mask was changed to a 0.003 inch wire cross, which reduced the intensity to about forty percent of its initial value. A scan of the m/e 28 region with the 0.003 inch cross is shown in Figure 15. In the same figure, the tail magnitude, as it would appear without a mask, is drawn approximately in the Y-axis.

TEST OF THE PHASE V QUADRUPOLE SYSTEM

Considerable effort was spent in testing and optimizing the first new quadrupole system. Every new test conducted with this system appeared to produce excellent data, much improved over the past quadrupole data of the earlier configurations. Figure 16 shows a typical linear scan of resolution versus tail slope, while Figures 17 through 21 show a scan over m/e 1 to 140. Note that the dynamic range of this system is over six decades.

The operation of this system is so good that resolution of CO_2^+ (M = 44.0039) and $C_3H_8^+$ (M = 44.0776) was possible, as shown in Figure 22. This separation requires a resolving power of over 605. Resolving powers of about 900 were obtained with this quadrupole.

The sensitivity of this quadrupole configuration was measured at about 1×10^{-7} amperes per torr. In order to increase the sensitivity, the second system (defined as S/N 02) was redesigned to increase the nozzle opening. The aperture was increased to 0.020 inch diameter and a roughly rectangular etched mask was placed at the nozzle exit. The mask has a geometry approximating a cross of 0.003 by 0.002 inch. This redesigned nozzle system was tested and found to possess a sensitivity of about 3.5×10^{-7} amperes per torr. This increase in sensitivity was, however, obtained at the expense of other parameters such as resolution, for example, the 100 percent transmission cutoff point for the first system is about m/e 90, while that for the second system was about m/e 60.

After testing the serial number 02 system, its cover was electron beam welded and the system underwent acceptance testing in December of 1969 with a typical scan shown in Figure 23. The unit was carried to GSFC by Goddard personnel on 17 December 1969. The acceptance data package for this system is provided in Appendix B.

The serial number 03 instrument consisted of the quadrupole rod assembly, from the first system tested, and a miniaturized open ion source.

Considerable testing was done with this unit in an attempt to optimize the mode of operation. The nozzle geometry of the open ion source was the same as the second unit, optimized for sensitivity and not for resolution. The sensitivity of the open ion source system was measured at approximately 1.7 x 10^{-7} amperes per torr. Typical of the optimization efforts is Figure 24, showing the variation of spectrum shape as a function of quadrupole biasing with respect to the accelerator. Figure 25 is a scan that was optimized over the entire mass spectrum shown.

The open ion source system (S/N 03) was hand carried to GSFC by Goddard personnel in February 1970. This unit was shipped nude (without the cover).

The third instrument, identified as serial number 01, consists of the dual filament ion source, which was tested from June to October of 1969, with the data shown in Figures 8 through 22 and a third set of rods and multiplier. Serial number 01 has the small nozzle aperture (0.010 inch) with the 0.003 inch wire cross as a mask.

Testing of serial number 01 was conducted in June of 1970 and after acceptance testing was hand carried to GSFC.

Most of the backup optimization data is enclosed in the Acceptance Test Procedure data package which is provided in Appendix C. A typical background spectrum is shown in Figure 26. A spectrum of air plus background is shown in Figure 27 with the data over the m/e 28 peak showing the amplitude change with change of high voltage in the electron multiplier. Figure 28 shows the same spectrum with the multiplier high voltage at -2900 volts. Figures 29 through 34 show the variation of spectrum shape with varying operating parameters. After the unit was welded to the cover the acceptance test was run and the data, as usual, improved somewhat because of the more efficient differential pumping. Figure 35 shows the last run taken of the final welded configuration.

At the same time that serial number 01 was delivered the third dual filament ion source was also delivered fully assembled and having a nozzle geometry identical to that of unit serial number 02.

CONCLUSIONS

The Quadrupole Mass Spectrometers developed under this contract have attained the highest operating performance of any of the previously designed systems generated under the earlier contracts.

Empirical data has shown that ion masking improves the performance of a quadrupole mass filter, as predicted by theory.

The unique design of an isolation mounted system on a baseplate proved very convenient in assembling and testing of the mass spectrometer system. This in turn necessitated a thicker housing, which increased the final weight of the system. The modular assembly developed under this contract has been applied, with modifications, to the design of the four inch rod quadrupole system.

Utilization of the deflector system incorporated into the electron multiplier has increased the dynamic range capability of the quadrupole analyzers. A dynamic range exceeding 10^6 has been easily obtained for the Phase V instrumentation.

The studies conducted under this contract have provided increased knowledge of the operation of the quadrupole system. It thus appears that further improvements may be made in the performance of this type of system.

The instruments which resulted from this developmental contract have shown a capability for the application of measuring the constituents of both planetary and the earth's atmospheres. One of these instruments is already scheduled for NASA's Planetary Atmosphere Experimental Test (PAET) flight. Another system (with some very slight modifications) has already been built for NASA Langley Research Center as a breadboard model for the Viking Martian Soil Analysis experiment.

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APPENDICES

APPENDIX A - Structural Analysis of Flight Quadrupole Mass Spectometer

APPENDIX B - Acceptance Data Package

APPENDIX C - Acceptance Test Procedure Data Package

APPENDIX A

STRUCTURAL ANALYSIS OF FLIGHT QUADRUPOLE MASS SPECTROMETER

APPENDIX A

Mechanical Development
16 May 1969

Contract #30001
Project Note #1

STRUCTURAL ANALYSIS OF FLIGHT QUADRUPOLE MASS SPECTROMETER

1.0 OBJECTIVE:

The objective of this project note is to show the structural integrity and the natural frequencies of the flight quadrupole mass spectrometer design when subjected to the following environments:

1.1 Acceleration load of 150 g's.

1.2 Resonance of the spacecraft to be at approximately 400 cps with a possible amplification factor of 5.

2.0 SUMMARY OF RESULTS:

All areas analyzed have been found to meet or exceed the design objectives.

2.1 Natural frequency of the system along each of the three axes. (Paragraph 3.1)

$f_n(X) = 3060$ cps
$f_n(Y) = 1050$ cps
$f_n(Z) = 1500$ cps

2.2 Flexure rod assembly analysis for allowable stress levels (paragraph 3.2).

2.3 Natural frequency of each hyperbolic rod (paragraph 3.3.2).

$f_n = 2430$ cps

2.4 Rod deflection at 150 g loading (paragraph 3.2.3).

$Y = 0.00046$ in.

2.5 Cinch strap analysis for allowable stress levels (paragraph 3.4).

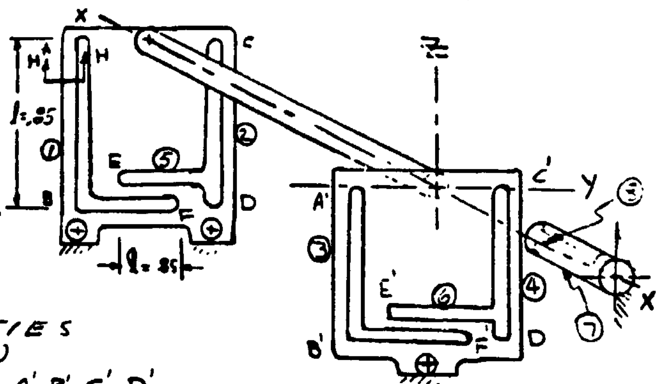
3.0 ANALYSIS AND CALCULATIONS:

APPENDIX A

BY J. DEANE DATE 5-14-69 SUBJECT QUADRUPOLE FLEXURE PLATE ANALYSIS SHEET NO 1 OF 37
CHKD. BY .... DATE .... JCA NO 30001
PROJECT NOTE #1

3.1

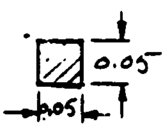
DETERMINE THE NATURAL FREQUENCIES OF THE SYSTEM ALONG EACH OF THE THREE AXES.



3.1.1
CONSIDER LOADING IN THE 'Z' DIRECTION.

ELASTIC PROPERTIES OF CROSS SECTION OF STRUTS A-B, C-D, A'-B', C'-D'

$k_1 = \frac{AE}{L}$ (STIFFNESS)



SECTION H-H (TYP)

$= \frac{(0.0025)(29 \times 10^6)}{0.85}$

$k_1 = 85.4 \times 10^3$ lb/IN

$E = 29 \times 10^6$ PSI

$A = (.05)(.05)$

$A = 0.0025$ IN^2

$k_1 = k_2 = k_3 = k_4$

$k_{T_{1-4}} = 4(k_1)$

$= 4(85.4 \times 10^3)$

$k_{T_{1-4}} = 341 \times 10^3$ lb/IN.

MASS OF SYSTEM

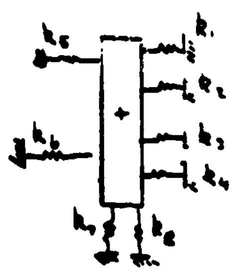
$W = 0.15 + 0.73 + 0.62$

$W = 1.5$ lb.

$m = \frac{W}{g}$

$= \frac{1.5 \text{ lb.}}{386 \text{ IN/SEC}^2}$

$m = 3.89 \times 10^{-3}$ $\frac{\text{lb-SEC}^2}{\text{IN}}$



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CHKD. BY DATE	FLEXURE PLATE ANALYSIS	JOB NO [illegible]
		P.N. # 1

NATURAL FREQUENCY OF MEMBERS UNDER DIRECT LOADING.

$$f_{n_{1\to4}} = \frac{1}{2\pi}\,\omega_n \qquad \omega_n = \sqrt{\frac{k}{m}}$$

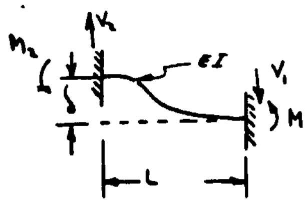
$$= \frac{1}{2\pi}(9.38 \times 10^3) \qquad = \sqrt{\frac{341 \times 10^3}{3.89 \times 10^{-3}}}$$

$$= 1.5 \times 10^3 \qquad \underline{\omega_n = 9.38 \times 10^3 \ \frac{RAD}{SEC}}$$

$$\underline{f_{n_{1\to4}} = 1500 \text{ CPS}}$$

ADD THE BENDING STIFFNESS OF HORIZONTAL MEMBERS EF & E'-F'

MOMENT & SHEAR BY SLOPE DEFLECTION.



ASSUMED SHAPE DUE TO BENDING

$$M_{1\to2} = M_{\text{fixed end}} + 2k\left[2\theta_1 + \theta_2 - 3\phi\right]$$

$$M_1 = M_2 = 2\frac{EI}{L}\left(-3\frac{\delta}{L}\right)$$

$$\underline{M_1 = -6\frac{EI}{L^2}\delta}$$

$$k = \frac{EI}{L}$$

$$\phi = \frac{\delta}{L}$$

$$\theta_1 = \theta_2 = 0$$

$$M_{\text{Load}} = 0$$

For SHEAR CALCULATIONS

$$V_1 L - 2\left(\frac{6EI\delta}{L^2}\right) = 0$$

$$\underline{\underline{V = \frac{12\,EI\delta}{L^3}}}$$

$$k = \frac{V}{\delta}$$

$$\underline{\underline{k = \frac{12EI}{L^3}}}$$

APPENDIX A

BY J.D. DATE	SUBJECT QUADRUPOLE	SHEET NO. 3 OF 37
CHKD. BY DATE	FLEXURE PLATE ANALYSIS	JOB NO. 30001
		P.N. #1

STIFFNESS FOR E-F ⑤, E'-F' ⑥

CROSS SECTION

$$I = \frac{1}{12} bh^3$$

$$= \frac{1}{12}(0.05)^4$$

$$\underline{I = 52.1 \times 10^{-8} \text{ IN}^4}$$

$$k_5 = \frac{12\,EI}{L^3}$$

$$= \frac{12\,(29\times10^6)(52.1\times10^{-8})}{(.85)^3}$$

$$\underline{k_5 = 295 \text{ LB/IN}}$$

$$k_6 = k_5$$

$$k_{T\,5+6} = k_5 + k_6$$

$$= 2(295)$$

$$= 590 \text{ LB/IN}$$

$$\underline{k_{5+6} = 0.59 \times 10^3 \text{ LB/IN}}$$

STIFFNESS OF FLEXURE ROD ASSY (341868-1) (TUBE ⑦ + ROD ⑧)

$$k_7 = \frac{2EI}{L^3}$$

$$= \frac{2\,(29\times10^6)(.315\times10^{-6})}{(1^3)}$$

$$\underline{k_7 = 18.2 \text{ LB/IN (TUBE)}}$$

$$I_7 = \frac{\pi}{64}(d_o^4 - d_i^4)$$

$$= \frac{\pi}{64}(.3^4 - .2^4)$$

$$\underline{I_7 = 0.315\times10^{-6} \text{ IN}^4}$$

$$k_8 = \frac{2EI}{L^3}$$

$$= \frac{2\,(29\times10^6)(3.2\times10^{-6})}{1^3}$$

$$\underline{k_8 = 180 \text{ LB/IN. (ROD)}}$$

$$I_8 = \frac{\pi d^4}{64}$$

$$= \frac{\pi}{64}(.09)^4$$

$$\underline{I_8 = 3.2\times10^{-6} \text{ IN}^4}$$

$$\underline{k_{7+8} = 198 \text{ LB/IN}}$$

BY J.D.	DATE	SUBJECT QUADRUPOLE	SHEET NO. 4 OF 37
CHKD BY	DATE	FLEXURE PLATE ANALYSIS	JOB NO. 30001
			P.N. #1

∴ DETERMINE THE NATURAL FREQUENCY OF THE SYSTEM ALONG THE 'Z' AXIS.

$$f_{n(z)} = \frac{1}{2\pi}\,\omega_n \qquad \omega_n = \sqrt{\frac{k_{1\to4} + k_{5\to6} + k_{7\to8}}{m}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{341\times10^{3}}{3.89\times10^{-3}}}$$

$$= \frac{9.36\times10^{3}}{2\pi}$$

$$\boxed{f_{n(z)} = 1500 \text{ CPS}}$$

$$k_{1-4} = 341\times10^{3}\ \text{LB/IN}$$

$$k_{5-6} = 0.59\times10^{3}$$

NEGLIGIBLE

$$k_{7-8} = 0.198\times10^{3}$$

NEGLIGIBLE

3.1.2
CONSIDER LOADING ALONG THE "X" AXIS.

BENDING STIFFNESS OF STRUTS AB, CD, EF, A'B', C'D', E'F'

$k_1 = \frac{12EI}{L^3}$

$k_1 = 295 \frac{LB}{IN}$ (FROM PREVIOUS CALCULATION FOR BENDING STIFFNESS)

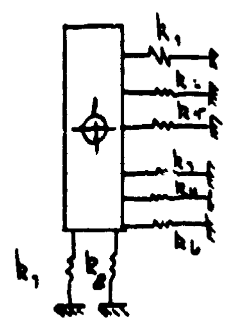
$k_1 = k_2 = k_3 = k_4 = k_5 = k_6$

$k_{1\to6} = 6(k_1)$

$= 6(295)$

$= 1{,}770$

$k_{1-6} = 1.77 \times 10^3 \ LB/IN$



ADD THE ELASTIC PROPERTIES OF THE FLEXURE ROD ASSY (341868-1)

(TUBE ① & ROD ②)

$k_7 = \frac{AE}{L}$

$= \frac{(0.044)(29 \times 10^6)}{1}$

$k_7 = 1.27 \times 10^6 \ LB/IN$

$A_7 = \frac{\pi}{4}(D^2 - d^2)$

$= \frac{\pi}{4}(.31^2 - .2^2)$

$A_7 = 0.044 \ IN^2$

$k_8 = \frac{AE}{L}$

$= \frac{(6.36 \times 10^{-3})(29 \times 10^6)}{1}$

$k_8 = 0.184 \times 10^6 \ LB/IN$

$A_8 = \frac{\pi d^2}{4}$

$= \frac{\pi}{4}(.09)^2$

$A_8 = 0.00636 \ IN^2$

$$k_{7-8} = k_7 + k_8$$

$$= (1.27 + 0.184) \times 10^6$$

$$\underline{k_{7-8} = 1.45 \times 10^6 \ LB/IN}$$

2. DETERMINE THE NATURAL FREQUENCY OF THE SYSTEM ALONG THE "X" AXIS.

$$f_{n(x)} = \frac{1}{2\pi} \omega_n \qquad \omega_n = \sqrt{\frac{k_{1-6} + k_{7-8}}{m}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{1.45 \times 10^6}{3.89 \times 10^3}}$$

$$\boxed{f_{n(x)} = 3060 \ CPS}$$

$k_{1-6} = 0.00177 \times 10^6$ LB/IN

NEGLIGIBLE

$k_{7-8} = 1.45 \times 10^6$ LB/IN

BY J.D. DATE .... SUBJECT QUADRUPOLE FLEXURE PLATE ANALYSIS SHEET NO. 7 OF 37
CHKD. BY ...... DATE .... JOB NO. 36002 P.U. #1

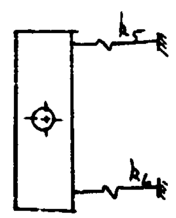
3.1.3
CONSIDER LOADING ALONG THE "Y" AXIS

ELASTIC PROPERTIES OF STRUTS EF, E'F'

$$k_5 = \frac{AE}{L}$$

$$= \frac{(0.0025)(29\times10^6)}{0.85}$$

$$\underline{k_5 = 85.4\times10^3 \text{ LB/IN}}$$



$$k_5 = k_6$$

$$k_{5-6} = 2(k_5)$$
$$= 2(85.4\times10^3)$$

$$\underline{k_{5-6} = 170.8\times10^3 \text{ LB/IN}}$$

ADD THE BENDING STIFFNESS OF THE SIDE MEMBERS AB, CD, A'B', C'D'

$$k_1 = \frac{12EI}{L^3}$$

$$= \frac{12(29\times10^6)(52.1\times10^{-8})}{(.85)^3}$$

$$\underline{k_1 = 295 \text{ LB/IN.}}$$

$$k_1 = k_2 = k_3 = k_4$$

$$k_{1\to4} = 4k_1$$
$$= 4(295 \text{ LB/IN})$$
$$= 1180 \text{ LB/IN.}$$

$$\underline{k_{1-4} = 1.18\times10^3 \text{ LB/IN}}$$

APPENDIX A

BY J. D. DATE	SUBJECT QUADRUPOLE	SHEET NO 8 OF 37
CHKD. BY DATE	FLEXURE PLATE ANALYSIS	JOB NO [illegible]
		F.D. [illegible]

2. DETERMINE THE NATURAL FREQUENCY OF THE SYSTEM ALONG THE "Y" AXIS.

$$f_n(y) = \frac{1}{2\pi}\,\omega_n \qquad \omega_n = \sqrt{\frac{k_{5-6} + k_{1-4}}{m}}$$

$$= \frac{1}{2\pi}\sqrt{\frac{(170.8 + 1.18)\times 10^{3}}{3.89 \times 10^{-3}}}$$

$$= 1.05 \times 10^{3}$$

$$\boxed{f_n(y) = 1050 \text{ CPS}}$$

$k_{5-6} = 170.8 \times 10^{3}$ LB/IN

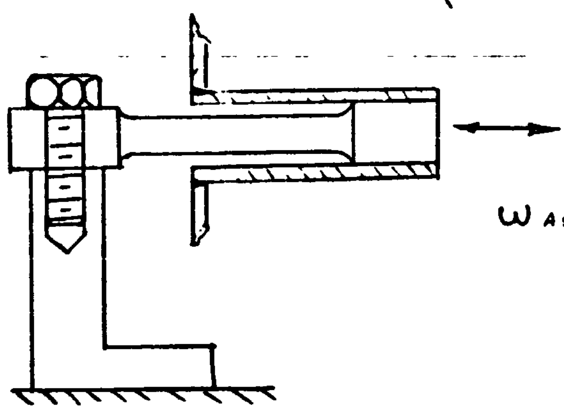
$k_{1-4} = 1.18 \times 10^{3}$ LB/IN

$m = 3.89 \times 10^{-3}$ $\frac{\text{LB SEC}^2}{\text{IN}}$

BY J. DEANE DATE 4-24-69 SUBJECT FLEXURE ROD ASSY. ANALYSIS SHEET NO. 9 OF 37
CHKD. BY ...... DATE .... JOB NO. 30301 P.N. #1

3.2 FLEXURE ROD ANALYSIS

DESIGN CRITERIA FOR FLEXURE ROD ASSY. (541369-1)



F = 360 LB.

$W_{ASSEMBLY} = 1.2$ lb.

$a = 300g$

3.2.1

CONSIDER THE DIA. OF BOLT REQ'D. FOR A TRANSVERSE SHEAR LOAD OF 360 LB.

$$S_{ys} = \frac{F_s}{A} \qquad A = \frac{\pi d^2}{4}$$

$S_{ys} = 33{,}000$ psi. 304 ANNEALED

$$33{,}000 = \frac{360}{\frac{\pi d^2}{4}}$$

$$d^2 = \frac{4}{\pi} \quad \frac{360 \times 10^{-3}}{33}$$

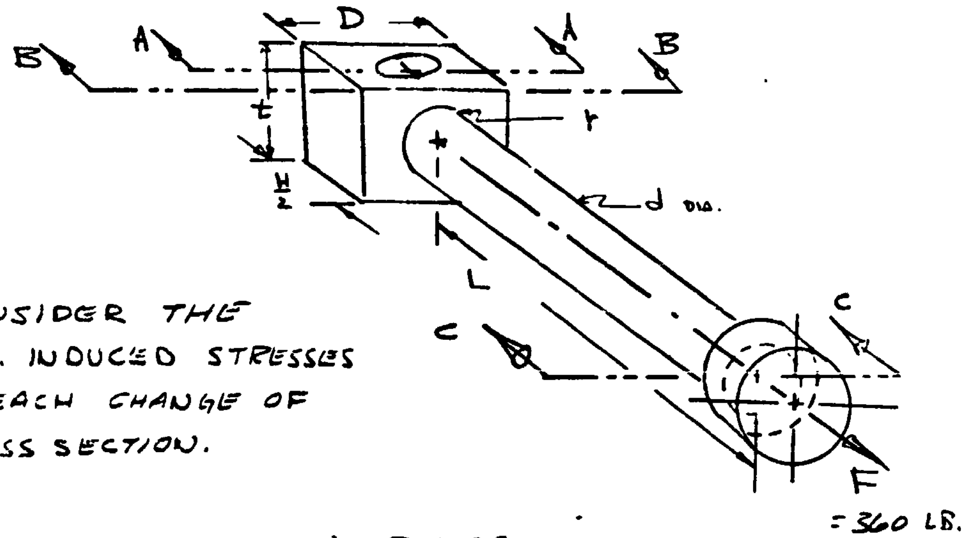
$\underline{d = 0.12 \text{ IN.}}$ MIN. BOLT DIA REQ'D. FOR 304 S.S. ANL. COND.

∴ USE # 8-32 304 S.S. ANNEALED

APPENDIX A

BY J.D. DATE 4-24-69 SUBJECT FLEXURE ROD ASSY. ANALYSIS SHEET NO. 10 OF 37
CHKD. BY ..... DATE ..... JOB NO. ..... P.N. #1

3.2.2

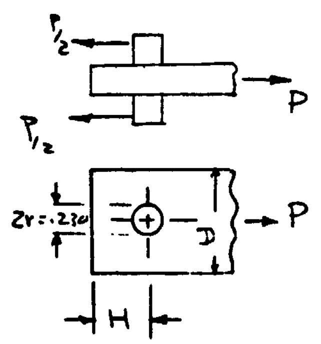


CONSIDER THE MAX. INDUCED STRESSES AT EACH CHANGE OF CROSS SECTION.

BASE DESIGN ON 304 S.S. ANNEALED CONDITION

SECTION A-A

CONSIDER INDUCED STRESSES AT 0.125" DIA. HOLE CROSS SECTION.



$$S_t = k\frac{P}{A} = \frac{(3.5)(360)}{0.068}$$

$$S_t = 18{,}500 \text{ PSI (REQ'D.)}$$

$$A = (D - 2r)t = (.57 - .23)(.2)$$

$$A = 0.068 \text{ IN}^2$$

$$\frac{H}{D} = \frac{0.20}{0.57}$$

$$\frac{H}{D} = 0.35$$

$$\frac{2r}{D} = \frac{.230}{.57}$$

$$\frac{2r}{D} = 0.40$$

$$K = 3.5$$

REF.
FIG. 2-9 P.74
DES. OF MACHINE ELEMENTS;
M.F. SPOTTS

BY J.D. DATE	SUBJECT FLEXURE ROD ASSY.	SHEET NO 11 OF 37
CHKD. BY DATE	ANALYSIS	JOB NO. 30501
		P.U. #1

THE TENSILE STRESS AVAILABLE FROM THE MATERIAL.

$S_{UT_{304}} = 85{,}000$ PSI

$\therefore S_{AVAIL.} \geq S_{REQ'D.}$

$\therefore$ STRONG ENOUGH

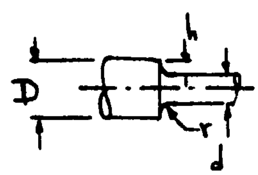
SECTION B-B

CONSIDER INDUCED STRESSES AT NECKED-SECTION.

$$S_t = K\frac{P}{A}$$

$$= 1.4\ \frac{360}{0.0063}$$

$$S_t = 79{,}500 \text{ PSI REQ'D.}$$



$$\frac{r}{d} = \frac{.05}{.09}$$

$$\frac{r}{d} = 0.55$$

$$\frac{h}{r} = \frac{0.055}{0.05}$$

$$\frac{h}{r} = 1.1$$

$S_{t_{304}} = 85{,}000$ PSI

AVAIL. FROM THE MATERIAL

$S_{t_{AVAIL}} > S_{t\ REQ'D.}$

$\therefore K = 1.4$ [REF FIG 2-4 SPOTTS]

$\therefore$ STRONG ENOUGH

SECTION C-C

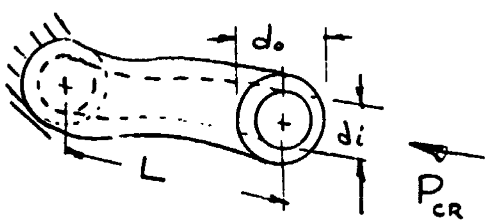
THE INDUCED STRESSES ARE THE SAME AS FOR SECTION B-B BECAUSE THE CROSS SECTIONS ARE THE SAME.

APPENDIX A

BY J.D. DATE .... SUBJECT FLEXURE ROD ASSY. SHEET NO 12 OF 37
CHKD. BY ...... DATE .... ANALYSIS JOB NO 30001
P.N. #1

CONSIDER THE CRITICAL LOAD FOR NO BUCKLING TO DETERMINE THE REQ'D CROSS SECTION AREA.

TUBE MATL: 304 S.S.-ANL. COND.



$L = 1.1$
$d_i = 0.2$
$P_{CR} = 360$ lb.

$$P_{CR} = \frac{4\pi^2 EI}{L^2}$$

$$I = \frac{P_{CR} L^2}{4\pi^2 E}$$

$$= \frac{360\,(1.1)}{4\pi^2 (28\times10^6)}$$

$$\underline{I = 0.315\times10^{-6}\ \text{IN}^4}\ \text{(REQ'D)}$$

$$I = \frac{\pi\,(d_o^4 - d_i^4)}{64}$$

$$d_o^4 - d_i^4 = \frac{64}{\pi}\,(.315\times10^{-6})$$

$$d_o = \sqrt{25.3\times10^{-4}} + 0.2$$

$$\underline{d_{o_{MIN.}} = 0.25\ \text{IN.}}$$

∴ MIN. WALL THICKNESS FOR NO BUCKLING

$$t = \frac{d_o - d_i}{2}$$

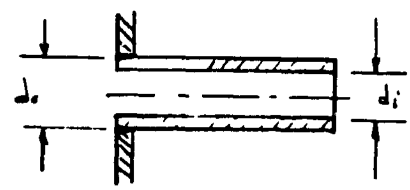
$$= \frac{.25 - .2}{2}$$

$$\underline{t_{MIN.} = 0.025\ \text{IN.}}\quad \text{(FOR NO BUCKLING)}$$

BY J.D. DATE	SUBJECT FLEXURE ROD ASSY. ANALYSIS	SHEET NO 13 OF 37
CHKD. BY DATE		JOB NO. [illegible] P.U. #1

SECTION D-D

CONSIDER INDUCED STRE[illegible] [illegible] (TENSION)



$$S_t = \frac{P}{A}$$

$$35{,}000 = \frac{360}{\frac{\pi(d_o^2 - d_i^2)}{4}}$$

$S_{yp} = 35{,}000$ PSI

30K

$$d_o^2 - d_i^2 = \frac{4(360)}{35{,}000\,\pi}$$

$d_i = 0.2$ IN.

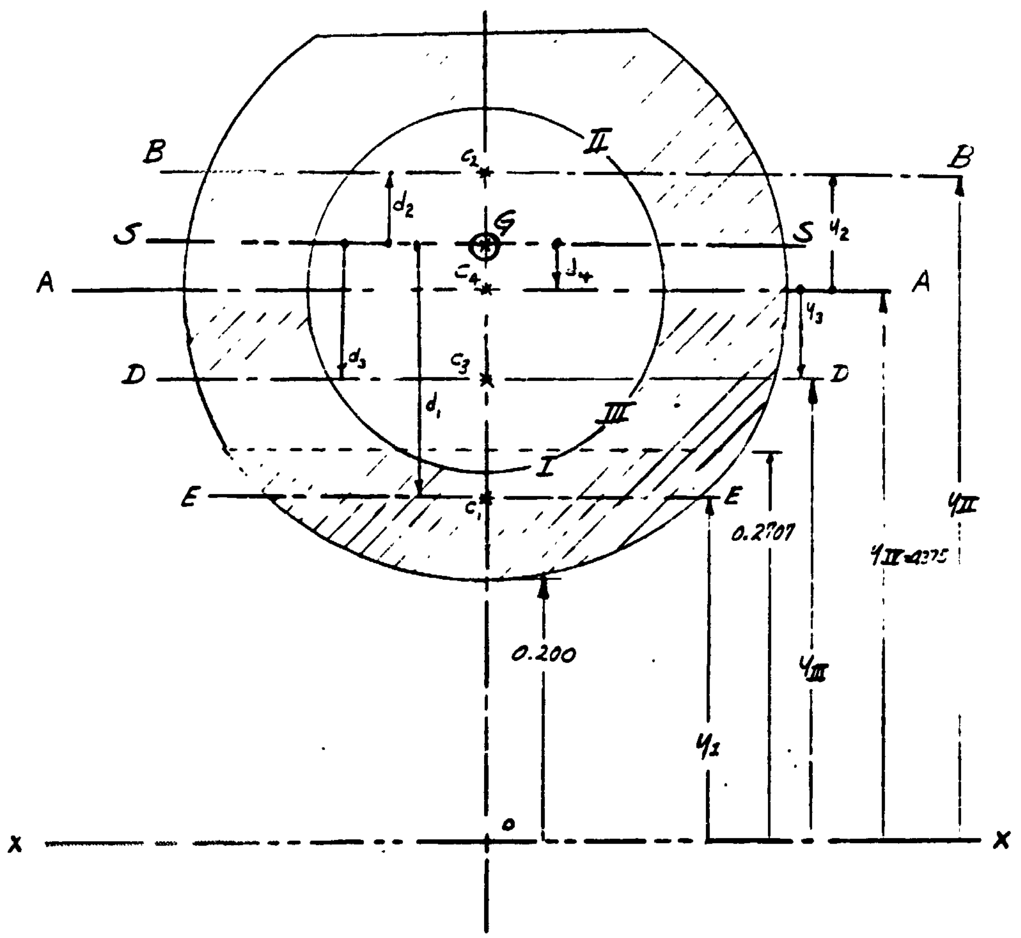
$$d_o - d_i = 0.11$$

$\underline{d_o = 0.31 \text{ IN.}}$ MIN. DIA REQ'D. FOR TENSION.

3.3 HYPERBOLIC ROD ANALYSIS

3.3.1

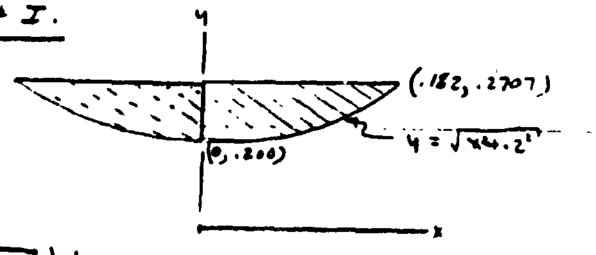
SECTION PROPERTIES:



APPENDIX A

BY DEANE DATE .... SUBJECT HYPERBOLIC ROD — SHEET NO 15 OF 37
CHKD. BY .... DATE .... JOB NO [illegible]
P.N. #1

<u>CONSIDER ELEMENT # I.</u>



AREA

$$\frac{A_I}{2} = \int_{x=0}^{x=.182}\int_{y=\sqrt{x^2+.2^2}}^{y=.2707} dy\,dx$$

$$A_I = 2\int_0^{.182}\left(.2707-\sqrt{x^2+.2^2}\right)dx$$

$$= 2\left[.2707x - \frac{1}{2}\left(x\sqrt{x^2+.2^2} + .2^2 \ln\left(x+\sqrt{x^2+.2^2}\right)\right)\right]_0^{.182}$$

$$= 2\left[.2707(.182) - \frac{1}{2}\left(.182\sqrt{.182^2+.2^2} + .2^2\ln\left(.182+\sqrt{.182^2+.2^2}\right) - .2^2\ln .2\right)\right]$$

$$= 2\left[.0475 - \frac{1}{2}\left(.049 - .0318 + .0642\right)\right]$$

$$= .095 - .0814$$

$$\underline{\underline{A_I = 0.014 \text{ IN.}^2}}$$

FIRST MOMENT

$$\frac{Q_{xx_I}}{2} = \int_{x=0}^{x=.182} \int_{y=\sqrt{x^2+.2^2}}^{y=.2707} y\,dy\,dx$$

$$Q_{xx_I} = 2\int_0^{.182} \frac{y^2}{2}\,dx \Bigg|_{\sqrt{x^2+.2^2}}^{.2707}$$

$$= 2\times\frac{1}{2}\int_0^{.182} (.2707)^2\,dx - (x^2+.2^2)\,dx$$

$$= .0732\,x - .04\,x - \frac{x^3}{3}\Bigg|_0^{.182}$$

$$= 0.0133 - 0.008 - 0.00201$$

$$\underline{\underline{Q_{xx_I} = 0.0033 \ IN^3}}$$

CENTROID

$$y_I = \frac{Q_{xx}}{A}$$

$$= \frac{0.0033}{0.014}$$

$$\underline{\underline{y_I = 0.236 \ IN.}}$$

BY DEAN... DATE...... SUBJECT HYPERBOLIC ROD ...... SHEET NO 17 OF 37
CHKD. BY...... DATE...... JOB NO. 50501
P.N. #1

SECOND MOMENT

$$\frac{I_{xx_I}}{2} = \int_{x=0}^{x=.182} \int_{y=\sqrt{x^2+.2^2}}^{y=.2707} y^2\,dy\,dx$$

$$I_{xx_I} = 2\int_0^{.182} \frac{y^3}{3}\Bigg|_{\sqrt{x^2+.2^2}}^{.2707}$$

$$= \frac{2}{3}\int_0^{.182} (.2707)^3 - \sqrt{(x^2+.2^2)^3}\,dx$$

$$= \frac{2}{3}\left[(.2707)^3 x - \frac{1}{4}\left[x\sqrt{(x^2+.2^2)^3} + \frac{3(.2)^2}{2} x\sqrt{x^2+.2^2} + \frac{3(.2)^4}{2}\ln\left(x+\sqrt{x^2+.2^2}\right)\right]\right]_0^{.182}$$

$$= \frac{2}{3}\left[(.0198)(.182) - \frac{1}{4}\left[(.182)(.0197) + (.06)(.182)(.27) + .0024\ln .425 - .0024\ln .2\right]\right]$$

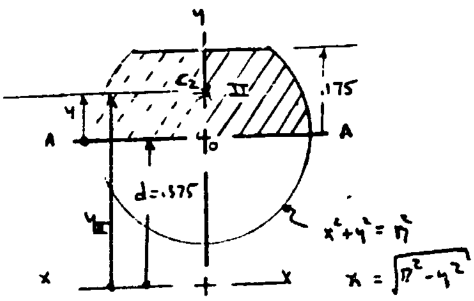
$$= \frac{2}{3}\left[0.0036 - \frac{1}{4}(0.0085)\right]$$

$$\underline{\underline{I_{xx_I} = 0.001 \text{ IN.}^4}}$$

APPENDIX A

BY ... DATE ... SUBJECT HYPERBOLIC ROD SHEET NO 18 OF 37
CHKD BY ... DATE ... JOB NO. 30001
P.D. #1

CONSIDER ELEMENT # II.



AREA

$$\frac{A_{II}}{2} = \int_{y=0}^{y=.175}\int_{x=0}^{x=\sqrt{r^2-y^2}} dx\,dy$$

$$A_{II} = 2\int_0^{.175}\sqrt{.21^2-y^2}\,dy$$

$$= 2 \times \frac{1}{2}\left[y\sqrt{.21^2-y^2} + (.21)^2 \sin^{-1}\frac{y}{.21}\right]_0^{.175}$$

$$= \left[.175\sqrt{.21^2-.175^2} + .21^2 \sin^{-1}\frac{.175}{.21}\right]$$

$$= (.175)(.114) + .0044 \sin^{-1} \overset{56.3^\circ}{.833}$$

$$= .0198 + .044(.984)$$

$$\underline{\underline{A_{II} = 0.0631 \text{ in}^2}}$$

FIRST MOMENT

$$\frac{Q_{AA_{II}}}{2} = \int_{y=0}^{y=.175} \int_{x=0}^{x=\sqrt{r^2-y^2}} y\,dx\,dy$$

$$Q_{AA_{II}} = 2\int_0^{.175} y\sqrt{.21^2-y^2}\,dy$$

$$= 2\left[-\frac{1}{3}\sqrt{(.21^2-y^2)^3}\right]_0^{.175}$$

$$= -\frac{2}{3}\left[\sqrt{(.21^2-.175^2)^3} - \sqrt{(.21)^6}\right]$$

$$= -\frac{2}{3}\left[\sqrt{(.0442-.0306)^3} - .21\right]$$

$$= -\frac{2}{3}\left(\sqrt{(.0136)^3} - .0094\right)$$

$$= -\frac{2}{3}(.00158 - .0094)$$

$$\underline{Q_{AA_{II}} = 0.0052\ IN.^3}$$

CENTROID

$$y_2 = \frac{Q_{AA_{II}}}{A_{II}}$$

$$= \frac{.0052}{.0631}$$

$$\underline{y_2 = 0.083\ IN.}$$

$$y_{II} = d + y_2$$

$$= .375 + 0.083$$

$$\underline{y_{II} = 0.458\ IN.}$$

SECOND MOMENT

$$\frac{I_{AA_{II}}}{2} = \int_{y=0}^{y=.175} \int_{x=0}^{x=\sqrt{.21^2-y^2}} x^2\,dx\,dy$$

$$I_{AA_{II}} = 2\int_0^{.175} \frac{x^3}{3}\Big|_0^{\sqrt{.21^2-y^2}} dy$$

$$= 2 \times \frac{1}{3}\int_0^{.175} \sqrt{(.21^2-y^2)^3}\,dy$$

$$= \frac{2}{3}\left[\frac{1}{4}\left(y\sqrt{(.21^2-y^2)^3} + \frac{3(.21)^2}{2}\,y\sqrt{\cancel{.21^2-y^2}}^{\,.114} + \frac{3(.21)^2}{2}\sin^{-1}\frac{y}{.21}\right)\right]_0^{.175}$$

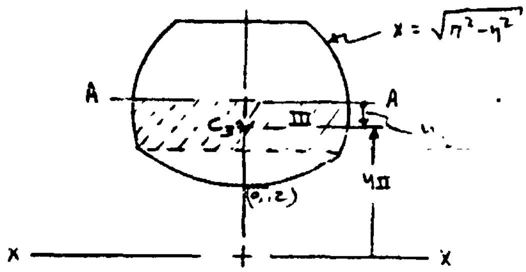
$$= \frac{1}{6}\left[(.175)(.00562) + (.066)(.171)(.114) + \frac{3}{2}(.00195)\sin^{-1}\left(\frac{.175}{.21}\right)\right]$$

$$= \frac{1}{6}\left[0.00098 + 0.00131 + 0.00288\right]$$

$$= \frac{1}{6}\left[0.00517\right]$$

$$I_{AA_{II}} = 0.000863 \quad IN^4$$

CONSIDER ELEMENT # III.



AREA

$$\frac{A_{III}}{2} = \int_{y=0}^{y=0.104} \int_{x=0}^{x=\sqrt{r^2-y^2}} dx\,dy$$

$$A_{III} = 2\int_0^{.104} \sqrt{.21^2 - y^2}\,dy$$

$$= 2 \times \frac{1}{2}\left[y\sqrt{.21^2 - y^2} + .21^2 \sin^{-1}\frac{y}{.21} \right]_0^{.104}$$

$$= .104\sqrt{.21^2 - .104^2} + (.21)^2 \sin^{-1}\frac{.104}{.21}$$

$$= (.104)(.182) + (.044)\sin^{-1}\underset{29.65^\circ}{.495}$$

$$= .0189 + .0228$$

$$\underline{A_{III} = .0417 \ IN^2}$$

BY DEAUL	DATE	SUBJECT HYPERBOLIC ROD	SHEET NO. 22 OF 37
CHKD. BY	DATE		JOB NO. 30001
			P.N. #1

FIRST MOMENT

$$\frac{Q_{AA_{III}}}{2} = \int_{y=0}^{y=.104} \int_{x=0}^{x=\sqrt{r^2-y^2}} y\,dx\,dy$$

$$Q_{AA_{III}} = 2\int_0^{.104} y\sqrt{.21^2-y^2}\,dy$$

$$= 2\left[-\frac{1}{3}\sqrt{(.21^2-y^2)^3}\right]_0^{.104}$$

$$= -\frac{2}{3}\left[\sqrt{(.21^2-.104^2)^3}-\sqrt{(.21)^6}\right]$$

$$= -\frac{2}{3}\left[\sqrt{(.0442-.0108)^3}-(.21)^3\right]$$

$$= -\frac{2}{3}\left[.0061-.0094\right]$$

$$\underline{Q_{AA_{III}} = 0.0022 \text{ IN}^3}$$

CENTROID

$$y_3 = \frac{Q_{AA_{III}}}{A_{III}}$$

$$= \frac{0.0022}{0.0417}$$

$$\underline{y_3 = 0.053 \text{ IN.}}$$

$$y_{III} = d - y_3$$

$$= .375 - .053$$

$$\underline{y_{III} = 0.322 \text{ IN.}}$$

BY DEAUL DATE SUBJECT HYPERBOLIC ROD SHEET NO. 23 OF 37
CHKD. BY DATE JOB NO. 50001
P.D. #1

SECOND MOMENT

$$\frac{I_{AA_{III}}}{2} = \int_{y=0}^{y=.104} \int_{x=0}^{x=\sqrt{r^2-y^2}} x^2 \, dx \, dy$$

$$I_{AA_{III}} = 2 \int_0^{.104} \frac{x^3}{3} \Big|_0^{\sqrt{.21^2-y^2}} dy$$

$$= 2 \times \frac{1}{3} \int_0^{.104} \sqrt{(.21^2-y^2)^3} \, dy$$

$$= \frac{2}{3} \times \frac{1}{4} \left[y\sqrt{(.21^2-y^2)^3} + \frac{3(.21)^2}{2} y \sqrt{.21^2-y^2} + \frac{3(.21)^4}{2} \sin^{-1} \frac{y}{.21} \right]_0^{.104}$$

$$= \frac{1}{6} \left[.104\sqrt{(.0334)^3} + (.066)(.104)(.182) + (.00292)(.518) \right]$$

$$= \frac{1}{6} \left[0.000635 + 0.00125 + 0.00151 \right]$$

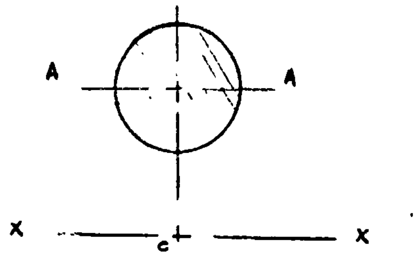
$$\underline{I_{AA_{III}} = 0.000565 \ \text{IN}^4}$$

APPENDIX A

BY DEANE . . DATE . . . SUBJECT HYPERBOLIC ROD SHEET NO 24 OF 37
CHKD. BY . . . DATE . . . JOB NO. 30021
P.N. #1

CONSIDER ELEMENT # IV.

AREA



$$A_{IV} = \pi r^2$$
$$= \pi(.125)^2$$
$$A_{IV} = 0.049 \text{ IN}^2$$

$$I_{AA_{IV}} = \frac{\pi r^4}{4}$$
$$= \frac{\pi}{4}(.125)^4$$
$$= \frac{\pi}{4}(.000244)$$
$$I_{AA_{IV}} = 0.000192 \text{ IN}^4.$$

DETERMINE THE MOMENT OF INERTIA OF THE ELEMENTAL AREAS ABOUT THEIR RESPECTIVE AXES.

ELEMENT # I

$$I_{xx_I} = I_{EE_I} + A_I(y_I)^2$$
$$I_{EE_I} = I_{xx_I} - A_I(y_I)^2$$
$$= 0.001 - (0.014)(.236)^2$$
$$= 0.001 - 0.00078$$
$$I_{EE_I} = 0.00022 \text{ IN}^4.$$

BY .... DATE	SUBJECT HYPERBOLIC ROD	SHEET NO. 25 OF 37
CHKD. BY .... DATE		JOB NO. 30001
		P.N. # 1

ELEMENT #2

$$I_{BB_{II}} = I_{AA_{II}} - A_{II}(y_2)^2$$

$$= 0.000863 - (.0631)(.083)^2$$

$$I_{BB_{II}} = 0.000428 \text{ IN}^4$$

ELEMENT #3

$$I_{DD_{III}} = I_{AA_{III}} - A_{III}(y_3)^2$$

$$= 0.000565 - (0.0417)(.053)^2$$

$$= 0.000565 - 0.000117$$

$$I_{DD_{III}} = 0.000448 \text{ IN}^4$$

ELEMENT #4

$$I_{AA_{IV}} = 0.000192 \text{ IN}^4$$

DETERMINE THE AXIAL MOMENT OF INERTIA OF THE CROSS SECTION ABOUT THE CENTROIDAL AXIS (S-S) PARALLEL TO THE X-X AXIS.

LOCATE THE CENTROID OF THE COMPOSITE CROSS SECTION.

$$\Sigma(A)Y = \Sigma(Ay)$$

$$Y(A_1+A_2+A_3+A_4) = (A_1y_1 + A_2y_2 + A_3y_3 + A_4y_4)$$

$$Y = \frac{(.014)(.236) + (.0631)(.458) + (.0417)(.322) - (.049)(.375)}{.014 + .0631 + .0417 - .049}$$

$$= .0027 + .0289 + .0131 - .0184$$

$$\underline{Y = 0.381 \text{ IN.}}$$ CENTROID OF COMPOSITE AREA

DETERMINE THE DISTANCES (d) FROM THE COMPOSITE CENTROID TO THE CENTROID OF EACH ELEMENTAL AREA.

$d_1 = y_I - Y$
$= .236 - .381$
$\underline{d_1 = .145 \text{ IN.}}$

$d_2 = y_{II} - Y$
$= .458 - .381$
$\underline{d_2 = 0.077 \text{ IN.}}$

$d_3 = y_{III} - Y$
$= .322 - .381$
$\underline{d_3 = 0.059 \text{ IN.}}$

$d_4 = y_{IV} - Y$
$= .375 - .381$
$\underline{d_4 = 0.006 \text{ IN.}}$

BY DEANE DATE 5-12-69 SUBJECT HYPERBOLIC ROD SHEET NO 27 OF 37
CHKD. BY .... DATE .... JOB NO. 55201
P.N. # 1

$$I_{SS} = (I_{EE_I} + A_{II} d_1^2) + (I_{EE_{II}} + A_{II} d_2^2) + (I_{DD_{III}} + A_{III} d_3^2) + (I_{AA_{IV}} + A_{IV} d_4^2)$$

$$= (0.00022 + (.014)(.145)^2) + (.00428 + (.0631)(.077)^2) +$$

$$((.000448) + (.0417)(.059)^2) + (.00192 + (.049)(.0\text{-}6)^2)$$

$$= .00051 + .00078 + .00056 - .00019$$

$$= 0.0016$$

$$\underline{\underline{I_{SS} = 1.6 \times 10^{-3} \text{ IN}^4.}}$$ (MOMENT OF INERTIA OF THE COMPOSITE AREA ABOUT ITS CENTROIDAL AXIS.)

APPENDIX A

BY J. D. DATE ... SUBJECT HYPERBOLIC ROD — NATURAL FREQUENCY DEFLECTION

CHKD. BY ... DATE ...

SHEET NO 28 OF 37 JOB NO 30001 P.D. #1

3.3.2

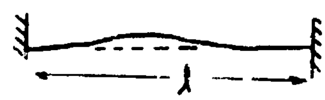
NATURAL FREQUENCY FOR FIXED ENDS

$$f_n = \frac{\omega_n}{2\pi}$$

$$= \frac{a_n}{2\pi}\sqrt{\frac{EI}{m l^4}}$$

$$= \frac{22}{2\pi}\sqrt{\frac{(25\times10^6)(1.6\times10^{-3})}{(6.36\times10^{-4})(6.0)^4}}$$

$$f_n = 2430 \quad CPS$$



$a_n = 22.0$

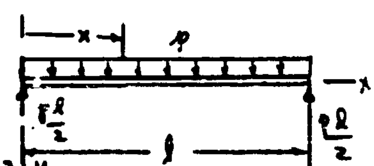
$l = 6"$

REF:
ANALYSIS OF STRESS & DEF.
HOUSNER & VREELAND

3.3.3

BEAM DEFLECTION FOR UNIFORM LOADING (w)

@ 150 g



BENDING MOMENT AT (X).

$$M_{x2} = -\frac{pl}{2}x + \frac{px^2}{2} \quad \left[\begin{matrix}\text{Center point}\\ x = 3 \text{ in.}\end{matrix}\right]$$

$$= -\frac{3.67(6)(3)}{2} + \frac{(3.67)(3)^2}{2}$$

$$M_{x2} = -16.5 \text{ LB-IN.}$$

$$p = \frac{w}{g}a$$

$$= \frac{.0245}{g}(150 g)$$

$$p = 3.67 \text{ LB/IN}$$

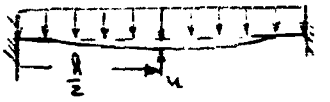
APPENDIX A

BY J.D. DATE SUBJECT HYPERBOLIC ROD SHEET NO. 29 OF 37

CHKD BY DATE RUN = 1

BEAM DEFLECTION (u) FOR FIXED ENDS.

$$u = \frac{k\,p\,l^4}{24EI}\left[\frac{x}{l} - 2\left(\frac{x}{l}\right)^3 + \left(\frac{x}{l}\right)^4\right]$$



$a_{in.} = 1$

$$u_{max} = \frac{\Delta_{in.}}{384}\frac{p\,l^4}{EI}$$

FOR MIDPOINT $x = \frac{l}{2}$

$$= \frac{1}{384}\frac{(3.67)(6)^4}{(25\times10^6)(1.07\times10^{-3})}$$

$u_{max.} = 0.00046$ IN. (FIXED ENDS)

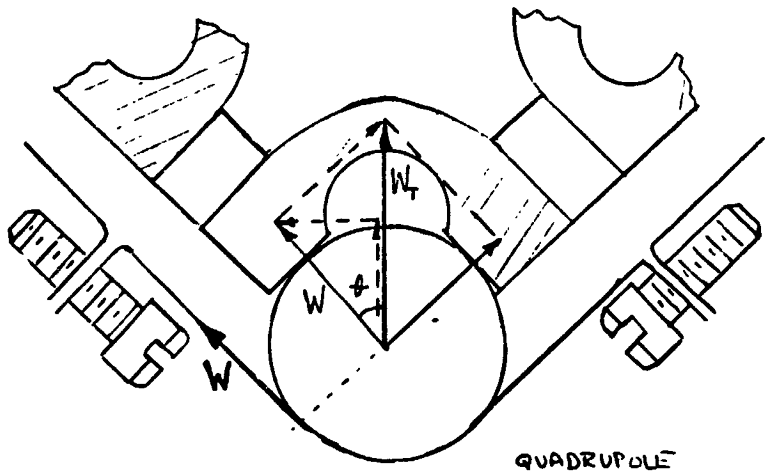
APPENDIX A

BY J. DEANE DATE 4-16-69 SUBJECT CINCH STRAP ANALYSIS SHEET NO 30 OF 37
CHKD BY ..... DATE ...... JOB NO. ...

3.4 CINCH STRAP ANALYSIS

FIND THE REQUIRED TENSION IN THE CINCH STRAP TO PREVENT SLIPPING BETWEEN THE HYPERBOLIC RODS AND THE QUADRUPOLE LOCATING DISC.

HYPERBOLIC ROD (MAT'L 404 S.S)



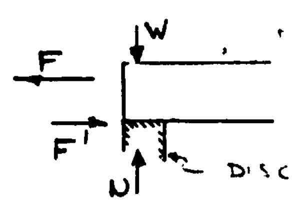
QUADRUPOLE LOCATING DISC (MAT'L: Al_2O_3)

CONSIDER LOADING OF 150g FINALLY
wt OF ROD = 0.15 lb.

$$\because \quad F = \frac{W}{g} a$$

$$= \frac{.15}{g} \; 150g$$

$$\underline{F = 22.5 \text{ lb.}}$$



SIDE VIEW OF ROD

$$\Sigma F_v = 0 = -W + N$$

$$\Sigma F_H = 0 = -F + F'$$

$$\underline{F' = 22.5 \text{ lb.}}$$

WHERE
$F' = \mu N$ (STATIC)

* STATIC COEFF. OF FRICTION BETWEEN THE TWO SURFACES $\mu = 0.78$

APPENDIX A

BY J. D. DATE	SUBJECT CINCH STRAP ANALYSIS	SHEET NO 31 OF 37
CHKD. BY DATE		JOB NO 52991
		P.N. #1

$$0 = -F + \mu N$$

$$= -F + \mu W$$

$$W = \frac{F}{\mu}$$

$$= \frac{22.5}{0.78}$$

$$\underline{W = 28.9 \text{ lb.}}$$ REQ'D. TO PREVENT SLIPPING

$$\frac{W}{W_T} = \cos\phi$$

$$W_T = \frac{28.9}{\cos 45^\circ}$$

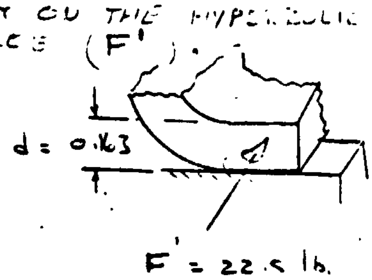
$$\underline{W_T = 40.8 \text{ lb.}}$$

CONSIDER THE LIMITING MOMENT ON THE HYPERBOLIC ROD RESULTING FROM THE FORCE (F').

$$M = F'd$$

$$= 22.5\ (0.163)$$

$$\underline{M = 3.66 \text{ in.-lb.}}$$



BY J.D. DATE ...... SUBJECT CINCH STRAP ANALYSIS SHEET NO. 32 OF 37
CHKD. BY ...... DATE ...... JOB NO. 30001
P.N #1

CONSIDER THERMAL EXPANSION AND ITS EFFECT ON THE STRAP TENSION.

TEMP PARAMETERS

$T_1 = 30°F \qquad T_2 = 250°F$

COEFF OF THERMAL EXPANSION

$\alpha_{304\,SS} = 10.0 \times 10^{-6}$ IN/IN/°F

$\alpha_{Al_2O_3\,\perp} = 5.5 \times 10^{-6}$ IN/IN/°F $\qquad \perp$ TO AXIS

$\alpha_{404\,SS} = 6.0 \times 10^{-6}$ IN/IN/°F

AVE THERMAL EXTENSIONAL STRAIN FOR THE STRAP

$$\bar{\epsilon}_x = \alpha\, \Delta Q$$
$$= 10.0 \times 10^{-6}(250-30)$$
$$= 2.20 \times 10^{-3}$$
$$\bar{\epsilon}_x = 0.0022 \ \tfrac{IN}{IN} \quad \text{AXIAL}$$

RESULTING STRAP ELONGATION (e)

$$\bar{\epsilon}_x = \frac{L^*}{L} - 1 = \frac{e}{L} \qquad L = 0.563 \text{ IN.}$$

$$e_{STRAP} = \bar{\epsilon}_x L$$
$$= (2.2 \times 10^{-3}\ IN)(0.563)$$
$$e_{STRAP} = 0.00124 \text{ IN}$$

BY J.D.	DATE	SUBJECT CINCH STRAP ANALYSIS	SHEET NO. 33 OF 37
CHKD. BY	DATE		JOB NO. 20001
			P.N. #1

RUBY INSULATOR (Al_2O_3)

AVE. THERMAL TRANSVERSE STRAIN

$$\bar{\epsilon}_r = \alpha_\perp \Delta Q$$

$$= (5.5 \times 10^{-6})(250^\circ - 30^\circ)$$

$$\bar{\epsilon}_r = 0.00121 \text{ IN/IN}$$

RESULTING THERMAL EXPANSION

$$\bar{\epsilon}_r = \frac{d^*}{d} - 1 = \frac{e}{d}$$

INITIAL DIA.
$d = 0.400$

$$\bar{e}_{r_{Al_2O_3}} = \bar{\epsilon}_r d$$

$$= 1.21 \times 10^{-3} \text{ IN/IN} (0.40)$$

$$\bar{e}_{r_{Al_2O_3}} = 0.000485 \text{ IN.}$$

HYPERBOLIC ROD (MODEL 404)

INDUCED THERMAL STRAIN

$$\bar{\epsilon}_{404} = \alpha_{404} \Delta Q$$

$$= 6.0 \times 10^{-6} (250 - 30)$$

$$\bar{\epsilon}_{404} = 1.32 \times 10^{-3} \text{ IN/IN}$$

APPENDIX A

BY J.D. DATE	SUBJECT CINCH STRAP ANALYSIS	SHEET NO. 34 OF 37
CHKD. BY DATE		JOB NO. 3000.1
		P.N. #1

RESULTING THERMAL EXPANSION

INITIAL HEIGHT
$H = 0.175$
H^{*} = EXPANDED HEIGHT

$$\bar{\epsilon}_{404} = \frac{H^{*}}{H} - 1 = \frac{e}{H}$$

$$e_{ROD} = \bar{\epsilon} H$$

$$= 1.32 \times 10^{-3} (0.175)$$

$$e_{\substack{ROD \\ 404}} = 0.231 \times 10^{-3} \text{ IN.}$$

RESULTING NET CHANGE IN EXPANSION

$$e_{NET} = e_{STRAP} - \left(e_{Al_2O_3} + e_{ROD}\right)$$

$$= 0.00124 - (0.000485 + 0.000231)$$

$$e_{NET} = 0.00052 \text{ IN} \qquad \text{EXPANSION}$$

NET REDUCTION IN TENSILE STRAIN ($\bar{\epsilon}$) DUE TO THERMAL EXPANSION.

$L = 0.563$

$$\bar{\epsilon}_{NET} = \frac{e_{NET}}{L}$$

$$= \frac{0.00052}{0.563}$$

$$\bar{\epsilon}_{NET} = 0.92 \times 10^{-3} \text{ IN/IN}$$

NET REDUCTION IN TENSILE STRESS $(\bar{\sigma}_x)$ DUE TO THERMAL EXPANSION.

$$E = \frac{\bar{\sigma}_x}{\bar{\epsilon}_x}$$

$$\bar{\sigma}_{x_{304}} = E\,\bar{\epsilon}_x$$

$$= (28 \times 10^6 \text{ psi})(0.92 \times 10^{-3} \tfrac{\text{in}}{\text{in}})$$

$$\bar{\sigma}_{x_{304}} = 25.8 \times 10^3 \text{ PSI}$$

THIS IS THE ADDITIONAL STRESS WHICH MUST BE INTRODUCED IN THE STRAP IN ORDER TO MAINTAIN THE REQUIRED TENSILE LOAD ($W_{LB.}$).

CONSIDER THE REDUCED TENSILE LOAD DUE TO THERMAL EFFECTS.

$$\sigma_x = \frac{P}{A}$$

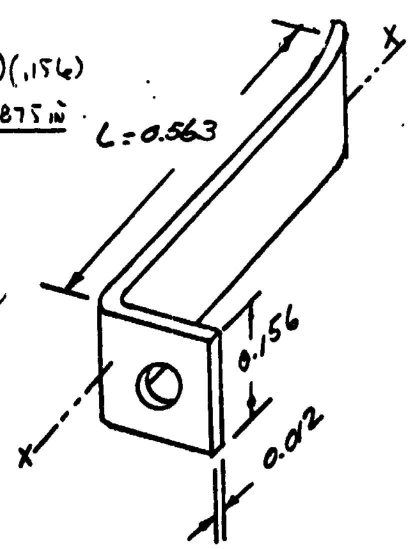
$A = (.012)(.156)$

$A = 0.001875 \text{ in}^2$

$$P = \sigma_x A$$

$$= (25.8 \times 10^3)(1.875 \times 10^{-3})$$

$$P = 48.4 \text{ LB.} \quad \text{(THERMAL LOAD)}$$



∴ THE TOTAL TENSILE LOAD REQUIRED TO OVERCOME THERMAL EXPANSION IS: .

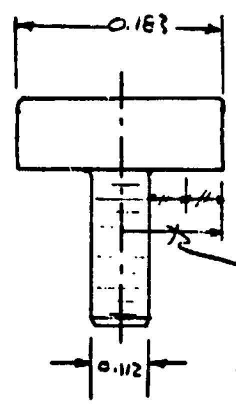
$$W_{NET} = W_{FRICT} + P_{THERMAL}$$

$$= 28.9 \text{ lb.} + 48.4 \text{ lb.}$$

$$\underline{W_{NET} = 77.3 \text{ lb.}}$$ (MIN. REQ'D. TENSILE LOAD)

DETERMINE THE MINIMUM SCREW SIZE NECESSARY TO PROVIDE THE MINIMUM TORQUE REQUIRED TO MAINTAIN THE STRAP TENSILE LOAD.

TRY # 4-40 CAP SCREW



COEFF. OF FRICT. [illegible] C.

$\mu_{SS \text{ on } S.S.} = 0.78$

HEAD DIA. = 0.183 IN

THD. O.D. = 0.112 IN.

PITCH DIA. = 0.0[illegible] IN.

$\mu_c = 0.78$

R_c = COLLAR RADIUS

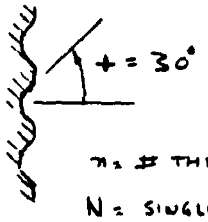
$$= \frac{0.112}{2} + \left(\frac{0.183 - .112}{4}\right)$$

$$\underline{R_c = 0.073 \text{ IN.}}$$

APPENDIX A

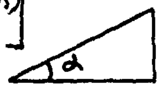
BY J.D.	DATE	SUBJECT CINCH STRAP ANALYSIS	SHEET NO. 37 OF 37
CHKD. BY	DATE		JOB NO. 30001
			P.U. # 1

MINIMUM TORQUE REQ'D. TO MAINTAIN STRAP TENSILE LOAD.



$$T = W\frac{D_m}{2}\left[\frac{\tan\alpha + \frac{\mu}{\cos\psi}}{1-\frac{\mu}{\cos\psi}\tan\alpha} + \mu_c R_c\right]$$

$$= 77.3\left(\frac{0.095}{2}\right)\left[\frac{.086+\frac{.78}{\cos 30°}}{1-\frac{.78}{\cos 30°}(.086)} + (.78)(.073)\right]$$



$T_{MIN.} = 7$ IN. LB.

MIN. REQ'D. TORQUE

$PITCH = \frac{1}{n}$

$PITCH = \frac{1}{40}$

ALLOWABLE TORQUE FOR #4-40 CAP SCREW, ALLEN HEAD IS 7 → 9 IN. LB.

$LEAD = N\ PITCH$

$= 1\left(\frac{1}{40}\right)$

$LEAD = \frac{1}{40}$

$\tan\alpha = \frac{LEAD}{\pi D_m}$

$= \frac{1/40}{\pi(0.095)}$

$\tan\alpha = 0.086$

∴ USE #4-40 ALLEN HEAD CAP SCREW

APPENDIX A

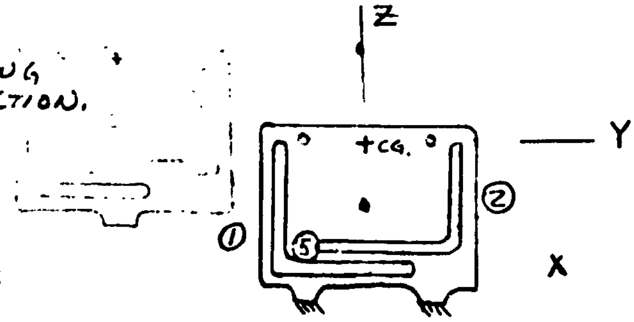
J. DEANE
7-16-69

QUADRUPOLE
FLEXURE PLATE
ANALYSIS

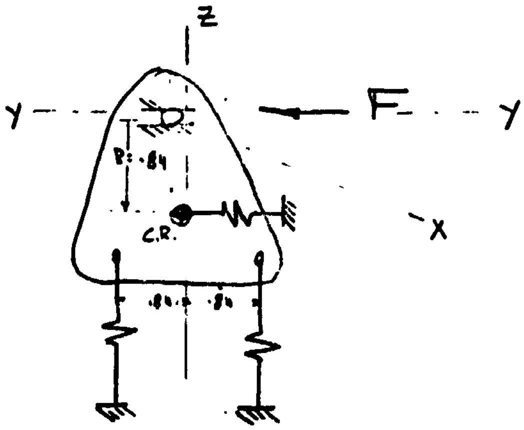
SHEET 1 OF 4
JOB: 30001
PROJECT NOTE # 1-A

CONSIDER THE FLEXURE PLATE SYSTEM FOR TWO DEGREES OF FREEDOM.
INVESTIGATE COUPLING AND ITS EFFECT ON THE NATURAL FREQUENCY OF THE SYSTEM.

CONSIDER LOADING IN THE 'Y' DIRECTION.



ELASTIC PROPERTIES OF CROSS SECTION.



$$k_s = \frac{AE}{L} = \frac{(0.0025)(29\times10^6)}{0.85}$$

$$k_s = 85.4\times10^3 \ \frac{LB}{IN}$$

CENTER OF ROTATION

$R = 0.34$ IN.

BENDING STIFFNESS OF STRUTS ① & ②

$$k_B = \frac{12EI}{L^3}$$

$$k_B = 295 \ LB/IN$$ (PREVIOUS CALCULATION 30001 PROJECT NOTE #1)

p. 2 of 4

FOR TRANSLATION

$$k_y = \sum_1^n k_i$$

$$= k_{5_E} + k_{1_E} + k_{7_E}$$

$$= 85.4 \times 10^3 + .295 \times 10^3 + .295 \times 10^3$$

$$\underline{k_y = 86.0 \times 10^3 \quad LB/IN}$$

FOR ROTATION

$$k_\phi = \sum_1^n k_i \cdot r_i^2$$

$$= k_{1_E} r^2 + k_{5_E} r^2$$

$$= 2(85.4 \times 10^3)(.84)^2$$

$$\underline{k_\phi = 120 \times 10^3 \ LB.-IN./RADIAN}$$

$$k_\phi = \frac{T}{\phi}$$

$$= \frac{Fr}{\phi}$$

$$= \frac{(k r \phi)(r)}{\phi}$$

$$\underline{k_\phi = k r^2}$$

INERTIA

$$J = \sum m r_i^2$$

$$= \frac{0.187\left(.42^2 + 2(.88)^2 + (1.17)^2\right)}{386 \ in/sec^2}$$

$$\underline{J = 1.5 \times 10^{-3} \ LB \cdot IN \cdot SEC^2}$$

$$m_1 = \frac{m}{4} \times \frac{1}{2}$$

$$= \frac{1.5}{4} \times \frac{1}{2}$$

$$\underline{m_1 = 0.187 \ lb.}$$

AMPLITUDE RATIOS

$$r^2 = \frac{k_\phi}{k_y}$$

$$= \frac{120 \ LB\text{-}IN}{86.0 \ LB/IN}$$

$$\underline{r^2 = 1.39 \ in^2}$$

$$r = \sqrt{1.39}$$

$$\underline{r = 1.18 \ in.}$$

$$\rho^2 = \frac{J}{m}$$

$$= \frac{1.5 \times 10^{-3} \text{ LB-IN-SEC}^2}{0.75 \text{ LB} \times \frac{1}{386 \text{ IN/SEC}^2}}$$

$$\rho^2 = 0.77 \text{ IN}^2$$

$$\rho = \sqrt{0.77}$$

$$\rho = 0.878 \text{ IN.}$$

$$\frac{r}{\rho} = \frac{1.18}{0.878}$$

$$\frac{r}{\rho} = 1.42$$

$$\frac{R}{\rho} = \frac{0.84}{0.878}$$

$$\frac{R}{\rho} = 0.956$$

NATURAL FREQUENCIES

(REF. ENGINEERING VIBRATIONS JACOBSEN/AYRE 1958 FIG. 7-16)

$$\frac{f_{1\,SYST.}}{f_Y} = 0.8$$

$$\frac{f_{2\,SYST.}}{f_1} = 1.85$$

$$f_Y = 1050 \text{ cps}$$

(PREVIOUS CALCULATION 30001 PROJ. NOTE # 1)

APPENDIX A

p.4 of 4

RESULTANT NATURAL FREQUENCIES

$$f_{1_y\,SYST} = 0.8\, f_y$$
$$= 0.8(1050)$$
$$\underline{\underline{f_{1_y\,SYST.} = 840 \text{ CPS}}}$$

$$f_{2_y\,SYST} = 1.85\, f_y$$
$$= 1.85(1050)$$
$$\underline{\underline{f_{2_y\,SYST.} = 1940 \text{ CPS}}}$$

$$f_\phi = \frac{1}{2\pi}\,\omega_\phi$$
$$= \frac{1}{2\pi}\left(9.13\times10^{3}\right)$$
$$\underline{\underline{f_\phi = 1450 \text{ CPS}}}$$

$$\omega_\phi = \sqrt{\frac{k_\phi}{J}}$$
$$= \sqrt{\frac{120\times10^{3}\ \text{LB-IN/RAD.}}{1.5\times10^{-3}\ \text{LB-IN-SEC}^2}}$$
$$\underline{\omega_\phi = 8.95\times10^{3}\ \frac{\text{RAD.}}{\text{SEC.}}}$$

APPENDIX A

BY H.D.C. DATE .... SUBJECT ROD LOCATING CERAMIC SHEET 1 OF 6
CHKD BY ... DATE ... 30001
PROJECT NOTE 2.

ADDENDUM I TO STRUCTURAL ANALYSIS OF FLIGHT QUADRUPOLE MASS SPECTROMETER.

1.0 OBJECTIVE:

ANALYSIS OF THE ROD LOCATING CERAMIC PLATES

2.0 RESULTS:

THE ANALYSIS SHOWS THAT THE STRESS LEVELS OF THE CERAMIC PLATES ARE WELL WITHIN THE STRENGTH OF THE MATERIAL USED.

APPENDIX A

3.0 ANALYSIS AND CALCULATIONS.

THE ROD LOCATING PLATE (P-E DWG C-341823) IS MADE FROM 95% ALUMINA WITH THE FOLLOWING MECHANICAL PROPERTIES:

$E = 40 \times 10^6$ PSI (MODULUS OF ELASTICITY)

$\sigma_{TU} = 30{,}000$ PSI (TENSILE ULTIMATE)

$\sigma_{bU} = 45{,}000$ PSI (BENDING ULTIMATE)

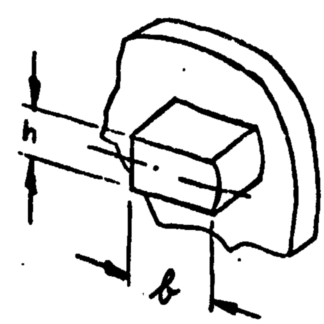
SECTION PROPERTIES OF ROD MOUNTING LUG.

WIDTH $= \dfrac{1.070 - \text{[illegible]}}{2} = 0.212$ INCH

THICKNESS $= 0.125$ INCH

MOMENT OF INERTIA ABOUT NEUTRAL AXIS.

$$I = \frac{b h^3}{12}$$



$$I = \frac{0.212 \times 0.125^3}{12}$$

$$I = \underline{\underline{3.45 \times 10^{-5}}}$$

3.1

CALCULATE THE MAXIMUM BENDING MOMENT, THAT CAN BE TRANSMITTED THROUGH THE SECTION.

$$\sigma = \frac{M}{I/c}$$

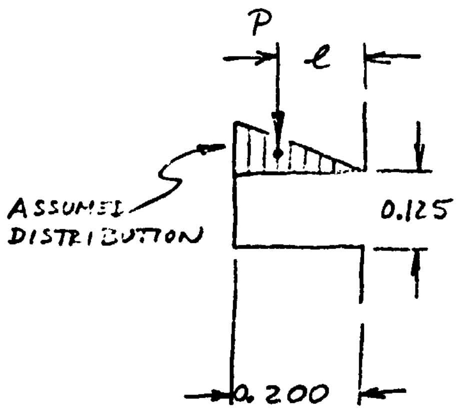
$$M = P\ell$$

BY HDC DATE ..... SUBJECT ROD LOCATING CERAMIC SHEET NO. 3 OF 6
CHKD. BY DATE JOB NO. 30001
PROJ. NOTE 2,
ADDENDUM I

$\ell = \left(\frac{2}{3}\right) 0.200$

$\ell = 0.133$ INCH

$c = \left(\frac{1}{2}\right) 0.125 = 0.0625$ INCH



$\sigma = \frac{P\ell}{I/c}$

SOLVE FOR P:

$P = \frac{\sigma I}{\ell c}$

$P = \frac{3.0 \times 10^{4} \times 3.45 \times 10^{-5}}{1.33 \times 10^{-1} \times 6.25 \times 10^{-2}}$

$P = \underline{\underline{125 \text{ lbs}}}$

THE LUG CAN SUPPORT 125 lbs.

3.2
WHEN THE SYSTEM IS ACCELERATED PERPENDICULAR TO THE CENTERLINES OF THE RODS THE MOUNTING LUG IS SUBJECTED TO THE MAXIMUM LOAD. FRICTION BETWEEN THE RODS AND THE CERAMICS IS NEGLECTED. ASSUME ½ THE INERTIAL LOAD OF EACH ROD IS REACTED BY THE MOUNTING LUG.

MAXIMUM STATICALLY EQUIVALENT ACCELERATION:

$W_1 = \frac{W}{2} = \frac{0.150}{2} = 0.075$ lbs

APPENDIX A

BY H.D.C. DATE ... SUBJECT ROD LOCATING CERAMIC SHEET NO 4 OF 6
CHKD BY ... DATE ... JOB NO 30001
PROJ. NOTE 2.
ADDENDUM I

$$P = ma = \frac{W}{g} ng$$

$$n = \frac{P}{W_1} = \frac{125}{0.075}$$

$$n = \underline{1670\ g}$$

IF A CONSERVATIVE STRESS CONCENTRATION FACTOR OF 2 IS INTRODUCED, THEN:

$$n = \underline{\underline{835\ g}}$$

3.3

A PROBABLE FAILURE MODE OF THE CERAMIC IS SHEAR IN THE LUGS.

SHEAR AREA:

$$A_S = 0.212 \times 0.125$$

$$A_S = 0.0265\ in^2$$

ASSUMED A SHEAR STRENGTH OF 50% OF THE ULTIMATE TENSILE.

$$\sigma_{su} = \frac{30{,}000}{2} = 15{,}000\ PSI$$

$$P = A_s\ \sigma_{su}$$

$$P = 0.0265 \times 15{,}000$$

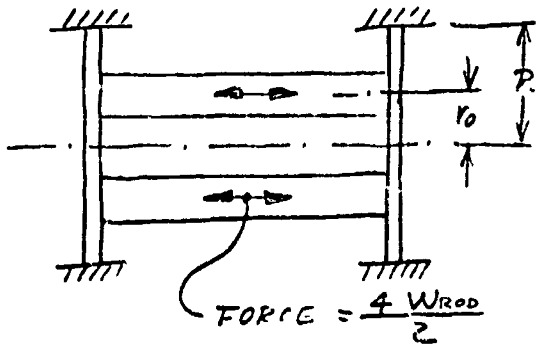
$$P = \underline{\underline{398\ lb.}}/LUG$$

A "WORST CASE" ASSUMPTION WOULD BE THAT ONE LUG REACTS THE WEIGHT OF ONE ROD,

$$\alpha = \frac{391}{0.150} = \underline{\underline{2650\ g}}$$

3.4
STRESS IN ROD MOUNTING CERAMIC DUE TO 30g SHOCK LOAD. TWO CERAMICS WILL CARRY THE LOAD.

ASSUMED A PLATE WITH FIXED BOUNDARY CONDITIONS, CIRCULAR CONCENTRATED LOAD ALONG ℄ OF RODS.



1) σ_{MAX} IS AT THE CENTER WHEN $r_0 < 0.31R$

2) σ_{MAX} IS AT THE EDGE WHEN $r_0 > 0.31R$

$r_0 = 0.37$
$R = 0.54$
$0.31 \times 0.54 = 0.167 < r_0$; CASE 2) APPLIES

$$\sigma_{MAX} = \frac{3W}{2\pi t^2}\left(1 - \frac{r_0^2}{R^2}\right)$$

$W = \frac{4 \times 0.15}{2} = 0.3$ lb.
$t = 0.125$ INCH

APPENDIX A

BY H.D.C. DATE ... SUBJECT ROD LOCATING CERAMIC SHEET NO. 6 OF 6
CHKD. BY ... DATE ... JOB NO. 30001
PROJ. NOTE 2.
ADDENDUM I

$$\sigma_{MAX} = \frac{3 \times 0.3}{2 \times \pi \times 0.125^2}\left(1 - \frac{0.37^2}{0.54^2}\right)$$

$$\sigma_{MAX} = 9.2\,(1 - 0.47) = 9.2 \times 0.53$$

$$\sigma_{MAX} = \underline{\underline{4.87\ \text{PSI}}} \ @\ 1g$$

$$\sigma_{MAX} = \underline{\underline{1460\ \text{PSI}}} \ @\ 300g$$

APPENDIX B

ACCEPTANCE DATA PACKAGE

APPENDIX B

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED

NAS5-11185

UNIT SERIAL NO. 002

Prepared By ________ Date 10-2-69
N. Ierokomos, Project Engineer

Approved By ________ Date 10-2-69
J. Schuster, Project Manager

Approved By ________ Date 10-2-69
J. Bly, Quality Assurrance Engineering

Approved By ________ Date 10-10-69

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANG ±0°30' DEC .XX ± .XXX ±	CONTRACT NO.	PERKIN-ELMER AEROSPACE SYSTEMS
MATERIAL:	DWG NO. DRAWN CHKD DESIGN	ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE
		SIZE A CODE IDENT NO. 26581 A-342269
		SCALE SHEET 1 of 16

F-134A

1. SCOPE

1.1 This document specifies the exact procedures to be followed in conducting the acceptance tests for the Martian Quadrupole, part number 341880, hereinafter referred to as the unit under test (UUT).

1.2 The acceptance tests shall be conducted to measure and determine the ion source and system sensitivities. The test parameters are specified at the applicable points in the following procedures.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of exact issue shown, form a part of this procedure to the extent specified herein. In the event of conflict between this procedure and documents referenced herein, this procedure shall govern.

MILITARY

MIL-C-45662A	Calibration System Requirements

NONMILITARY

SG 0091	General Specification for Malfunction Reporting, Analysis and Corrective Action

MANUFACTURING DRAWINGS

A341918	Electron Multiplier Specification
E341880	Analyzer Assembly
E341870	Ion Source Assembly, Dual Filament

3. TEST CONDITIONS AND EQUIPMENT

3.1 TEST CONDITIONS

3.1.1 All tests shall be conducted under ambient conditions unless otherwise specified herein.

3.2 TEST EQUIPMENT

3.2.1 The following items or their equivalent, are required to conduct the tests specified herein. All test equipment shall be calibrated per the appropriate calibration procedure and the next calibration due date shall be shown on a calibration decal.

E.G. Supply, Kepco ABC 425M
Spare Supply, Kepco ABC 425M
E.R. Supply, Kepco ABC 425M
F .. Ref. Supply, Kepco ABC 425M
Emission Req. Supply, Power Designs 4005
Oscillator B+, Dressen Barnes 5-300F
Oscillator Tube Filament Supply, Dressen Barnes 5-300F
Electron Multiplier Supply, John Fluke 408A
Multiplier 1st AP Supply, Northeast Scientific RE3002
Multiplier 2nd AP Supply, 90 V Battery

4. <u>TEST SEQUENCE AND SETUP</u>

4.1 TEST SEQUENCE

4.1.1 EXAMINATION OF PRODUCT. Visually inspect the UUT for any physical discrepancies or abnormalities.

4.1.2 CONFORMANCE TO DRAWINGS. The UUT shall be inspected for conformance to applicable drawings. In the event of discrepancies or abnormalities, the documents referenced herein shall govern.

4.1.3 FUNCTIONAL TESTS. Perform all tests in the sequence specified to ensure that the UUT conforms to the design specifications:

a. <u>Data Recording</u>. All test results are to be recorded on the test data sheets when specified by the test procedure.

b. <u>Failures</u>. In the event of a UUT failure at any point in the test procedure, the test shall stop and the reason for the failure shall be determined. The failure shall be entered into the system log book and the applicable failure reports shall be completed and given to the cognizant Quality Assurance Engineer. The UUT shall be kept in the clean room awaiting disposition.

4.2 TEST SETUP

4.2.1 The tests shall be conducted as shown in Figure 1, Test Setup.

5. TEST PROCEDURE

5.1 The following are step-by-step procedures for testing the UUT.

a. STEP

1. Ion Source Sensitivity. To measure the ion source sensitivity the following steps shall be followed:

(a) Admit a nitrogen sample to the vacuum system up to $5 \pm 1 \times 10^{-7}$ torr. Record actual pressure level on Test Data Sheet.

SIZE	CODE IDENT NO.	
A	26531	A-342269

F-135A

(b) Scan the analyzer over the top of the m/e 28 peak using electron gun number one, and record the current arriving at the first dynode of the electron multiplier (the first and second windows shall be at -45 Vdc) on Test Data Sheet. Record this scan on an X-Y plotter. Stamp Test Data Sheet.

(c) Admit a nitrogen sample to the vacuum system up to $2 \pm 1 \times 10^{-6}$ torr. Record actual pressure level on Test Data Sheet.

(d) Repeat Step (b) above.

(e) Repeat Steps (a) and (d) above using electron gun number two.

(f) Compute the ion source sensitivity, for nitrogen for each electron gun, by the following formula:

$$\text{Source Sensitivity} = \frac{I_{28}^{+}(@2 \times 10^{-6}\text{ torr}) - I_{28}^{+}(@\ 5 \times 10^{-7}\text{ torr})}{P(@\ 2 \times 10^{-6}\text{ torr}) - P(@\ 5 \times 10^{-7}\text{ torr})}$$

where:

I_{28}^{+} = the current measured at the first dynode of the electron multiplier.

P = actual pressure measured at the levels specified above.

The emission current is to be held constant. Record calculated source sensitivity and emission current on Test Data Sheet.

2. Peak Shape and System Sensitivity

(a) Using the two electron multiplier window biasing potentials, tune the m/e 28 peak shape. Monitoring the electron multiplier input current with -2000 Vdc applied to the second dynode and with the first dynode at the electron accelerator potential. Scan and record the peak on the X-Y plotter to analyze the peak shape. Stamp Test Data Sheet.

(b) Using the sensitivity determined for electron gun number one, measure the multiplier gain versus voltage using a nitrogen sample at $2 \pm 1 \times 10^{-6}$ torr in the vacuum system. Do this for multiplier voltages from -1500 to -2500 Vdc in 250 volt steps on the second dynode with the second window at 100 Vdc below the second dynode. Scan the m/e 28 peak of each step and compute the gain from the peak top. Record calculated gain on Test Data Sheet.

SIZE	CODE IDENT NO.	
A	20C31	A-342269
		SHEET 4 of 16

F-539A

(c) By turning the electron multiplier voltages, set the total analyzer sensitivity at between 5×10^{-2} and 5×10^{-1} amperes/torr.

(d) Using an air sample at 8×10^{-7} torr in the vacuum system, scan from below m/e 28 to above m/e 32, or conversely, and measure the peak resolution (excluding tails). This resolution should exceed m/m = 1/40 and is computed from

$$\Delta m/m = \frac{1}{7.5}\frac{B}{S}$$

where

B = base width distance

S = separation between the centers of the peaks.

Record actual resolution on Test Data Sheet.

3. Operating Parameters. Measure the potentials of the following electrodes with respect to ground at the levels specified in the above sections. Record all data on Test Data Sheet.

(a) Electron Gun #1

		ACTUAL
(1)	Filament Shield #1	-140. V
(2)	Electron Focus #1-A	-122. V
(3)	Electron Focus #1-B	-120. V
(4)	Electron Accelerator #1	0. V
(5)	Anode #1	0. V
(6)	Filament #1	-130. V

12-16-69
STAMP/DATE

SIZE	CODE IDENT NO.	
A	20C31	A-342269
SCALE		SHEET 5 of 16

F-135A

APPENDIX B

(b) Electron Gun #2 ACTUAL

(1) Filament Shield #2 -140 V

(2) Electron Focus #2-A -126. V

(3) Electron Focus #2-B -124. V

(4) Electron Accelerator #2 0. V

(5) Anode #2 0. V

(6) Filament #2 -130. V

12-16-69
STAMP/DATE

(c) Ion Source ACTUAL

(1) Repeller -30. V

(2) Accelerator -40. V

(3) Ion Focus A -103. V

(4) Ion Focus B -79. V

(5) Nozzle -330. V

12-16-69
STAMP/DATE

(d) Analyzer ACTUAL

(1) Quad Bias -40. V

12-16-69
STAMP/DATE

(e) Electron Multiplier ACTUAL

(1) Window #1 Bias -1528. V

(2) Window #2 Bias -1542. V

SIZE	CODE IDENT NO.	
A	20591	A-342269
SCALE		SHEET 6 of 16

F-135A

(a) (Cont)	ACTUAL
(3) First Dynode Bias (Positive)	0. V
(4) Second Dynode Bias (Negative)	−1650. V
	12-16-69 STAMP/DATE

4\. Measure the electron currents as follows:

(a) With Electron Gun #1 operating	ACTUAL
(1) Anode #1	15×10^{-6} A
(2) Electron Accelerator #1	45×10^{-6} A
(3) Electron Focus #1-A	0. A
(4) Electron Focus #1-B	0. A
(5) Electron Accelerator #2	0. A
(6) Anode #2	0. A
(7) Repeller	0. A
	12-16-69 STAMP/DATE

(b) With Electron Gun #2 operating	ACTUAL
(1) Anode #2	15×10^{-6} A
(2) Electron Accelerator #2	37×10^{-6} A
(3) Electron Focus #2-A	0. A
(4) Electron Focus #2-B	0. A
(5) Electron Accelerator #1	0. A
(6) Anode #1	0. A
(7) Repeller	0. A
	12-16-69 STAMP/DATE

SIZE	CODE IDENT NO.	
A	20501	A-342269
SCALE		SHEET 7 of 16

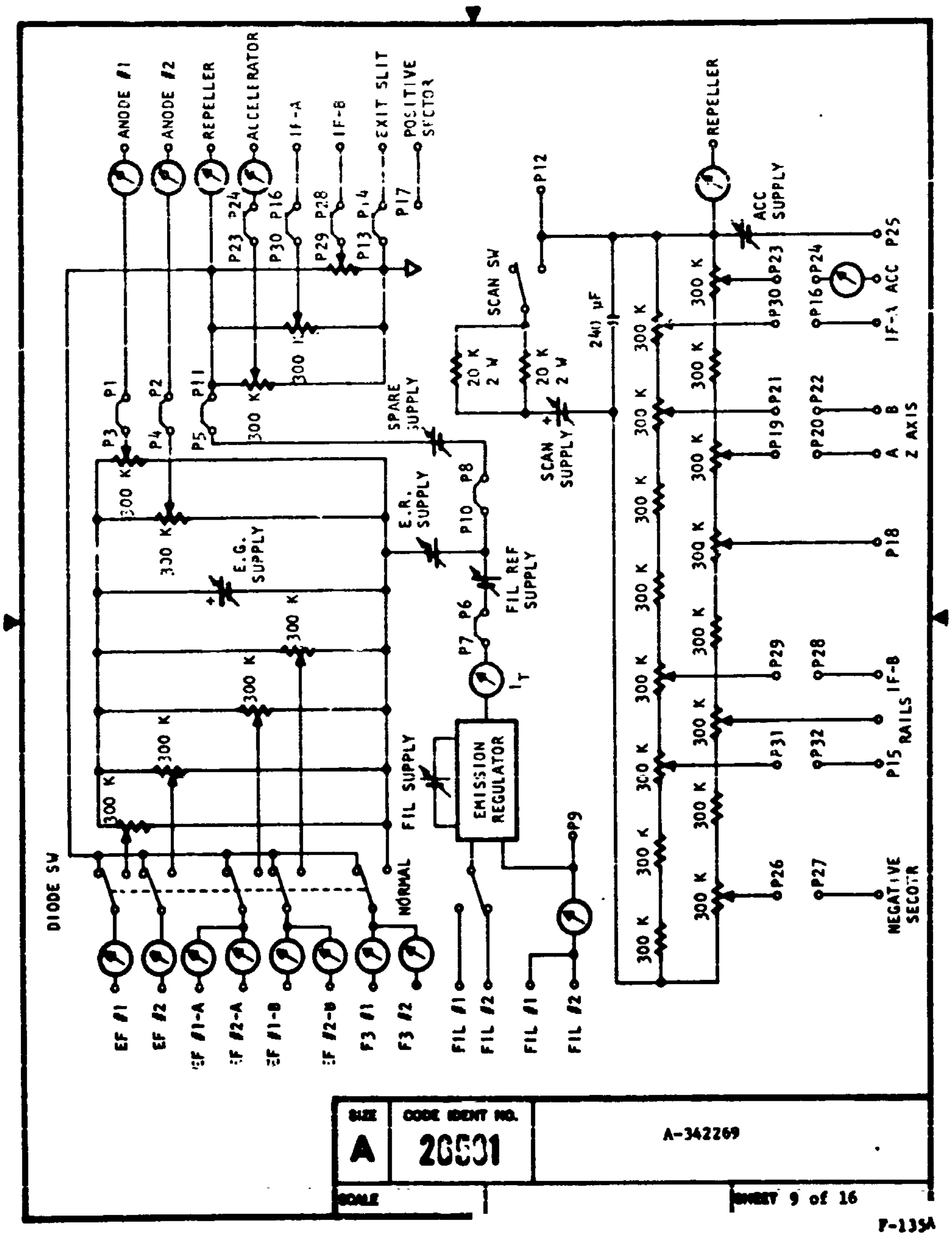
F-135A

5. Filament Characteristics. Measure the filament current and the voltage across both filaments, with all the electron gun electrodes connected to the repeller potential, and at a total emission collected of ~~400~~ 250 JEE microamperes. Record actual current and voltage measured on Test Data Sheet.

6. Dynamic Range. Measure the dynamic range from highest peak to lowest valley. Record data on Test Data Sheet.

SIZE	CODE IDENT NO.	
A	20501	A-342269
SCALE		SHEET 8 of 16

F-135A


SIZE
A
CODE IDENT NO.
20501
A-342269
SCALE
SHEET 9 of 16
F-135A

6. DATA SHEET

SERIAL NUMBER 002 — 12-16-69 STAMP/DATE

REF. PARA. 5 GUN #2

a. STEP

1(a)	Record pressure level	5.8×10^{-7} ACTUAL
		12-16-69 STAMP/DATE
(b)	Current at first dynode	3.8×10^{-13} A ACTUAL
		12-16-69 STAMP/DATE
	Scan recorded on X-Y plotter	12-16-69 STAMP/DATE
(c)	Record pressure level	9.75×10^{-7} ACTUAL
		STAMP/DATE
(d)	Current at first dynode	5.4×10^{-13} A ACTUAL
		12-16-69 STAMP/DATE
	Scan recorded on X-Y plotter	12-16-69 STAMP/DATE

NOTE: ANODE $I = 14 \times 10^{-6}$ AMPS

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20531	A-342269
SCALE		SHEET 10 of 16

F-13A

6. DATA SHEET (Cont)

SERIAL NUMBER 002 — 12-16-69 STAMP/DATE

REF. PARA. 5

a. STEP Gun #1

1(e)	Record pressure level	6×10^{-7} ACTUAL
		12-16-69 STAMP/DATE
	Current at first dynode	3.1×10^{-13} A ACTUAL
		12-16-69 STAMP/DATE
	Scan recorded on X-Y plotter	12-16-69 STAMP/DATE
	Record pressure level	9.6×10^{-7} ACTUAL
		12-16-69 STAMP/DATE
	Current at first dynode	4.1×10^{-13} A
		12-16-69 STAMP/DATE
	Scan recorded on X-Y plotter	12-16-69 STAMP/DATE
(f)	Calculated ion source sensitivity	#1 3.3×10^{-7} A/TORR #2 4.0×10^{-7} A/TORR ACTUAL
	Emission current	14×10^{-6} A ACTUAL
		12-16-69 STAMP/DATE

NOTE: ANODE CURRENT 14×10^{-6} AMPS

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20501	A-342269
SCALE		SHEET 12 of 16

F-135A

6. DATA SHEET (Cont)

SERIAL NUMBER 002 — 12-16-69 STAMP/DATE

REF. PARA. 5

a. STEP

2(a) Peak ~~scanned~~ measured on ~~X-Y plotter and peak shape analyzed~~ Keithley — 12-16-69 STAMP/DATE

(b) Calculated gain from peak top (m/e 28)

-1500 Vdc	1.9×10^3 ACTUAL
-1750 Vdc	7.5×10^3 ACTUAL
-2000 Vdc	2.4×10^4 ACTUAL
~~-2250 Vdc~~ -2100 Vdc	5.2×10^4 ACTUAL
~~-2500 Vdc~~ -1400 Vdc	1.7×10^3 ACTUAL

12-16-69 STAMP/DATE

(d) Peak resolution should exceed m/m = 1/40 — 1/42.7 ACTUAL

$\Delta\, m/m = \frac{1}{7.5}\ \frac{B}{S}$

12-16-69 STAMP/DATE

3. Electron potentials with respect to ground

(a) Electron Gun #1 — ACTUAL

(1) Filament Shield #1	-190. V
(2) Electron Focus #1-A	-122. V
(3) Electron Focus #1-B	-120. V

12-16-69 STAMP/DATE

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20531	A-342269
SCALE		SHEET 12 of 16

F-135A

6. DATA SHEET (Cont)

SERIAL NUMBER 002 — 12-16-69 STAMP/DATE

REF. PARA. 5

a. STEP

3(a) (Cont) — ACTUAL

(4) Electron Accelerator #1 — 0. V

(5) Anode #1 — 0. V

(6) Filament #1 — -130. V

12-16-69 STAMP/DATE

(b) Electron Gun #2 — ACTUAL

(1) Filament Shield #2 — -140. V

(2) Electron Focus #2-A — -126. V

(3) Electron Focus #2-B — -124. V

(4) Electron Accelerator #2 — 0. V

(5) Anode #2 — 0. V

(6) Filament #2 — -130. V

12-16-69 STAMP/DATE

(c) Ion Source — ACTUAL

(1) Repeller — -30. V

(2) Accelerator — -40. V

(3) Ion Focus A — -103. V

12-16-69 STAMP/DATE

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20501	A-342269
		SHEET 13 of 16

F-135A

6. DATA SHEET (Cont)

SERIAL NUMBER 002 — 12-16-69 STAMP/DATE

REF. PARA. 5

a. STEP

		ACTUAL
3(c)	(Cont)	
(4)	Ion Focus B	-79. V
(5)	Nozzle	-330. V
		12-16-69 STAMP/DATE
(d)	Analyser	ACTUAL
(1)	Quad Bias	-40. V
		12-16-69 STAMP/DATE
(e)	Electron Multiplier	ACTUAL
(1)	Window #1 Bias	-1528. V
(2)	Window #2 Bias	-1542. V
(3)	First Dynode Bias (Positive)	0 V
(4)	Second Dynode Bias (Negative)	-1650. V
		12-16-69 STAMP/DATE

4. Measure the electron currents as follows:

		ACTUAL
(a)	With Electron Gun #1 operating	
(1)	Anode #1	15×10^{-6} A
(2)	Electron Accelerator #1	45×10^{-6} A
(3)	Electron Focus #1-A	0 A
		12-16-69 STAMP/DATE

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20531	A-342269
SCALE		SHEET 14 of 16

F-135A

6. DATA SHEET (Cont)

SERIAL NUMBER 002

12-16-69
STAMP/DATE

REF. PARA. 5

a. STEP

4(a) (Cont)

	ACTUAL
(4) Electron Focus #1-B	0. A
(5) Electron Accelerator #2	0. A
(6) Anode #2	0. A
(7) Repeller	0. A

12-16-69
STAMP/DATE

(b) With Electron Gun #2 operating	ACTUAL
(1) Anode #2	15×10^{-6} A
(2) Electron Accelerator #2	37×10^{-6} A
(3) Electron Focus #2-A	0. A
(4) Electron Focus #2-B	0. A
(5) Electron Accelerator #1	0. A
(6) Anode #1	0. A
(7) Repeller	0. A

12-16-69
STAMP/DATE

5. Filament #1

Voltage 1.40 V
ACTUAL

Current 1.89 A
ACTUAL

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20501	A-342269

SHEET 15 of 16

F-135A

6. DATA SHEET (Concluded)

SERIAL NUMBER 002

12-16-69
STAMP/DATE

REF. PARA. 5

a. STEP

5. (Cont)

Filament #2

Voltage	1.39 V
Current	1.87 A
Total emission collected (400 μA)	250. μA

12-16-69
STAMP/DATE

6. Dynamic range from highest peak to lowest valley — $\geq 10^6$ ACTUAL

12-16-69
STAMP/DATE

Test Conducted By ____

Data Verified By ____

Concurrence By ____ DCAS QAR

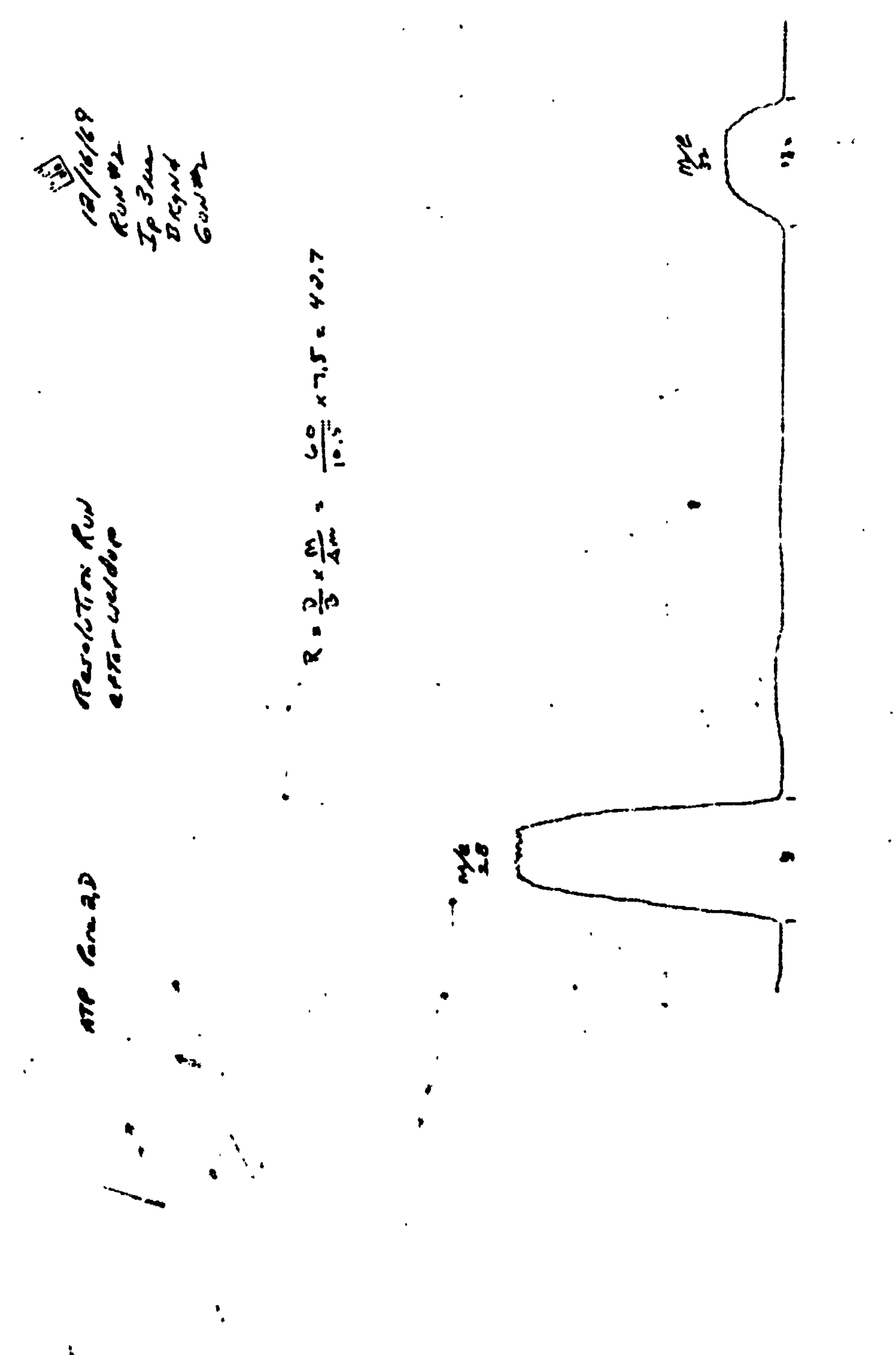
ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20001	A-342269
		SHEET 16 of 16

F-135A

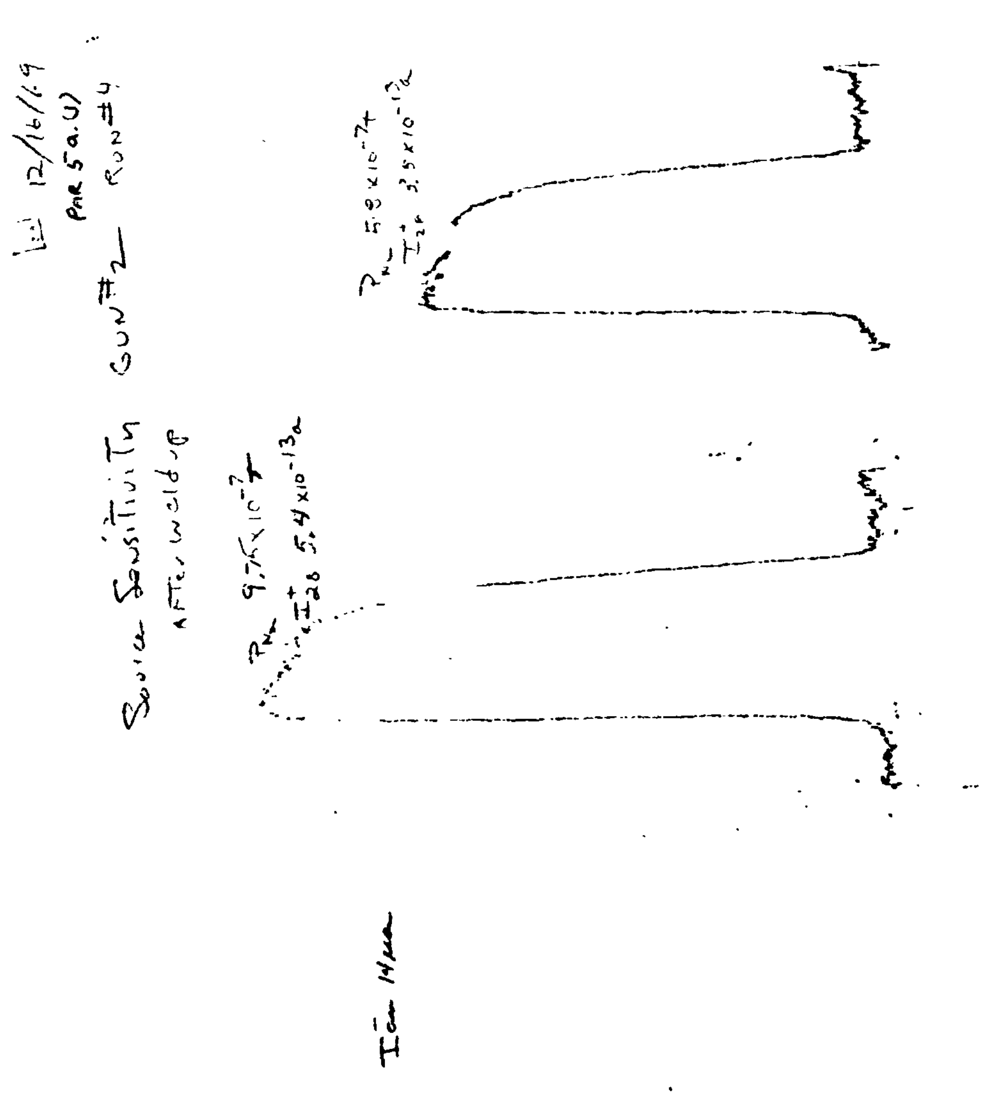
APPENDIX B

BY .... DATE .... SUBJECT ATP A342269 .... SHEET NO .... OF ....
CHKD. BY .... DATE .... JOB NO. ....



APPENDIX B

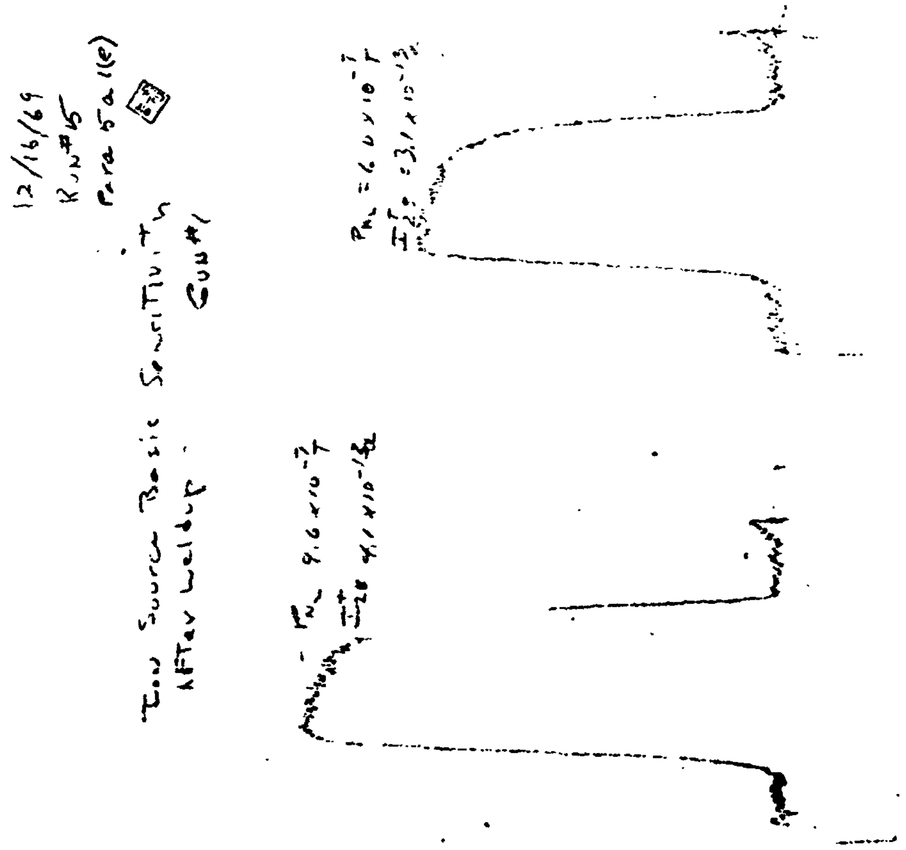
BY ...... DATE ...... SUBJECT ATP A 342269 SHEET NO ... OF ...
JOB NO ...
CHKD. BY. ... DATE. ......

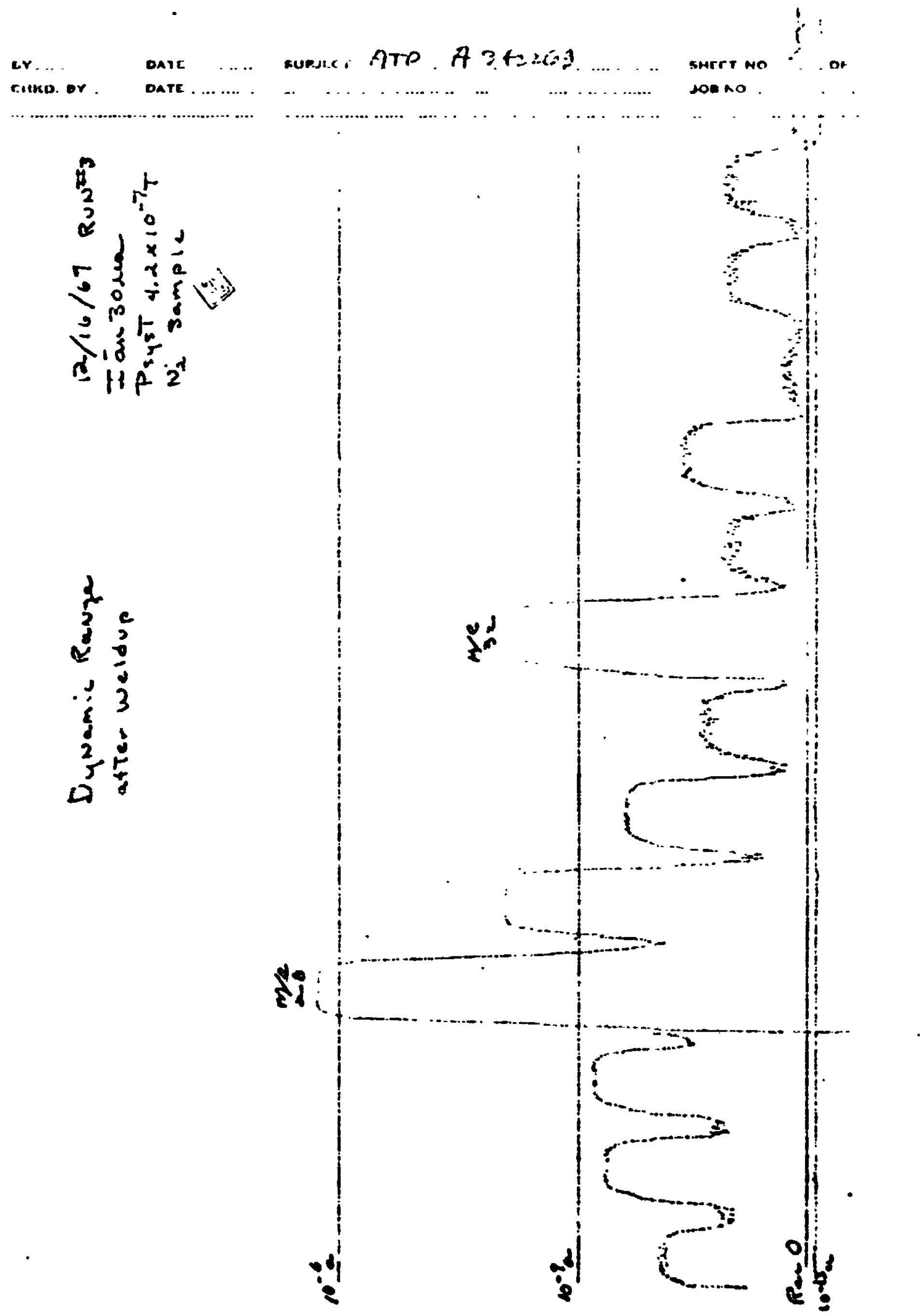


APPENDIX B

BY........ DATE........ SUBJECT RTP 43-2269 .... SHEET NO. 1 OF ....

CHKD. BY........ DATE........ .... JOB NO. ....




BY
DATE
SUBJECT ATP
SHEET NO
OF
CHKD. BY
DATE
JOB NO
12/16/67 Run #3
Dynamic Range
after weldup
m/e 32
m/e 28
Ref. 0

APPENDIX C

ACCEPTANCE TEST PROCEDURE DATA PACKAGE

APPENDIX C

APPLICATION		REVISIONS			
NEXT ASSY	USED ON	LTR	DESCRIPTION	DATE	APPROVED
		A	Revised ICO 25697	6/26/70	RD

NAS5-11185

UNIT SERIAL NO. 0001

Prepared By N. Yerolomos Date 6-26-70
N. Yerolomos, Project Engineer

Approved By R. Mealhow Date 6-26-70
R. Mealhow, Project Manager

Approved By Date 6-26-70
J. Bly, Quality Assurance Engineering

Approved By Jimmy E Cooley Date 6-26-70

Prepared for

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Goddard Space Flight Center
Greenbelt, Maryland

UNLESS OTHERWISE SPECIFIED DIMENSIONS ARE IN INCHES TOLERANCES ANG ±0°30' DEC .XX ± .XXX ±	CONTRACT NO. DWG NO.		PERKIN-ELMER AEROSPACE SYSTEMS
MATERIAL	DRAWN		ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE
	CHKD		
	DESIGN		
			SIZE A · CODE IDENT NO. 26531 · A-342269
			SCALE · SHEET 1 of 13

1. SCOPE

1.1 This document specifies the exact procedures to be followed in conducting the acceptance tests for the Martian Quadrupole, part number 341880, hereinafter referred to as the unit under test (UUT).

1.2 The acceptance tests shall be conducted to measure and determine the ion source and system sensitivities. The test parameters are specified at the applicable points in the following procedures.

2. APPLICABLE DOCUMENTS

2.1 The following documents, of exact issue shown, form a part of this procedure to the extent specified herein. In the event of conflict between this procedure and documents referenced herein, this procedure shall govern.

MILITARY

MIL-C-45662A	Calibration System Requirements

NONMILITARY

SC 0091	General Specification for Malfunction Reporting, Analysis and Corrective Action

MANUFACTURING DRAWINGS

A341918	Electron Multiplier Specification
E341880	Analyzer Assembly
E341870	Ion Source Assembly, Dual Filament

3. TEST CONDITIONS AND EQUIPMENT

3.1 TEST CONDITIONS

3.1.1 All tests shall be conducted under ambient conditions unless otherwise specified herein.

3.2 TEST EQUIPMENT

3.2.1 The following items or their equivalent, are required to conduct the tests specified herein. All test equipment shall be calibrated per the appropriate calibration procedure and the next calibration due date shall be shown on a calibration decal.

SIZE	CODE IDENT NO.	
A	26501	A-342269
SCALE		SHEET 2 of 13

Y-133

E.C. Supply, Kepco ABC 425M
Spare Supply, Kepco ABC 425M
E.R. Supply, Kepco ABC 425M
F.I. Ref. Supply, Kepco ABC 425M
Emission Req. Supply, Power Designs 4005
Oscillator B+, Dressen Barnes 5-300F
Oscillator Tube Filament Supply, Dressen Barnes 5-300F
Electron Multiplier Supply, John Fluke 408A
Multiplier 1st AP Supply, Northeast Scientific RE3002
Multiplier 2nd AP Supply, 90 V Battery

4. <u>TEST SEQUENCE AND SETUP</u>

4.1 TEST SEQUENCE

4.1.1 EXAMINATION OF PRODUCT. Visually inspect the UUT for any physical discrepancies or abnormalities.

4.1.2 CONFORMANCE TO DRAWINGS. The UUT shall be inspected for conformance to applicable drawings. In the event of discrepancies or abnormalities, the documents referenced herein shall govern.

4.1.3 FUNCTIONAL TESTS. Perform all tests in the sequence specified to ensure that the UUT conforms to the design specifications:

a. <u>Data Recording</u>. All test results are to be recorded on the test data sheets when specified by the test procedure.

b. <u>Failures</u>. In the event of a UUT failure at any point in the test procedure, the test shall stop and the reason for the failure shall be determined. The failure shall be entered into the system log book and the applicable failure reports shall be completed and given to the cognizant Quality Assurance Engineer. The UUT shall be kept in the clean room awaiting disposition.

4.2 TEST SETUP

4.2.1 The tests shall be conducted as shown in Figure 1, Test Setup.

5. TEST PROCEDURE

5.1 The following are step-by-step procedures for testing the UUT.

a. STEP

1. Ion Source Sensitivity. To measure the ion source sensitivity the following steps shall be followed:

(a) Admit a nitrogen sample to the vacuum system up to $5 \pm 1 \times 10^{-7}$ torr. Record actual pressure level on Test Data Sheet.

SIZE	CODE IDENT NO.	
A	26501	A-342269
SCALE		SHEET 3 of 13

F-135A

(b) Scan the analyzer over the top of the m/e 28 peak using electron gun number one, and record the current arriving at the first dynode of the electron multiplier (the first and second windows shall be at -45 Vdc) on Test Data Sheet. Record this scan on an X-Y plotter. Stamp Test Data Sheet.

(c) Admit a nitrogen sample to the vacuum system up to $2 \pm 1 \times 10^{-6}$ torr. Record actual pressure level on Test Data Sheet.

(d) Repeat Step (b) above.

(e) Repeat Steps (a) and (d) above using electron gun number two.

(f) Compute the ion source sensitivity, for nitrogen for each electron gun, by the following formula:

$$\text{Source Sensitivity} = \frac{I_{28}^{+}(@2 \times 10^{-6}\ \text{torr}) - I_{28}^{+}(@\ 5 \times 10^{-7}\ \text{torr})}{P(@\ 2 \times 10^{-6}\ \text{torr}) - P(@\ 5 \times 10^{-7}\ \text{torr})}$$

where:

I_{28}^{+} = the current measured at the first dynode of the electron multiplier.

P = actual pressure measured at the levels specified above.

The emission current is to be held constant. Record calculated source sensitivity and emission current on Test Data Sheet.

2. Peak Shape and System Sensitivity

(a) Using the two electron multiplier window biasing potentials, tune the m/e 28 peak shape. Monitoring the electron multiplier input current with -2000 Vdc applied to the second dynode and with the first dynode at the electron accelerator potential. Scan and record the peak on the X-Y plotter to analyze the peak shape. Stamp Test Data Sheet.

(b) Using the sensitivity determined for electron gun number one, measure the multiplier gain versus voltage using a nitrogen sample at $2 \pm 1 \times 10^{-6}$ torr in the vacuum system. Do this for multiplier voltages from -1500 to -2500 Vdc in 250 volt steps on the second dynode with the second window at 100 Vdc below the second dynode. Scan the m/e 28 peak of each step and compute the gain from the peak top. Record calculated gain on Test Data Sheet.

SIZE	CODE IDENT NO.	
A	26501	A-342269
SCALE		SHEET 4 of 13

F-135A

(c) By turning the electron multiplier voltages, set the total analyzer sensitivity at between 5×10^{-2} and 5×10^{-1} amperes/torr.

(d) Using an air sample at 8×10^{-7} torr in the vacuum system, scan from below m/e 28 to above m/e 32, or conversely, and measure the peak resolution (excluding tails). This resolution should exceed m/m = 1/40 and is computed from

$$\Delta m/m = \frac{1}{7.5}\frac{B}{S}$$

where

B = base width distance

S = separation between the centers of the peaks.

Record actual resolution on Test Data Sheet.

3. Operating Parameters. Measure the potentials of the following electrodes with respect to ground at the levels specified in the above sections. Record all data on Test Data Sheet.

(a) Electron Gun #1

		ACTUAL
(1)	Filament Shield #1	-141.5 v
(2)	Electron Focus #1-A	-131.8 v
(3)	Electron Focus #1-B	-134.5 v
(4)	Electron Accelerator #1	GND 0 v
(5)	Anode #1	0 v
(6)	Filament #1	-134.7 v

6/28/70
STAMP/DATE

SIZE	CODE IDENT NO.	
A	2G5S01	A-342269
SCALE		SHEET 5 of 11

F-135

(b) Electron Gun #2

	ACTUAL
(1) Filament Shield #2	-142.2 v
(2) Electron Focus #2-A	-130.4 v
(3) Electron Focus #2-B	-126.8 v
(4) Electron Accelerator #2	0 v
(5) Anode #2	0 v
(6) Filament #2	-135.3 v

6/28/70
STAMP/DATE

(c) Ion Source

	ACTUAL
(1) Repeller	-34.6 v
(2) Accelerator	-46.2 v
(3) Ion Focus A	-86.9 v
(4) Ion Focus B	-149
(5) Nozzle	-316.1 v

6/28/70
STAMP/DATE

(d) Analyzer

	ACTUAL
(1) Quad Bias	-45.9 v

6/28/70
STAMP/DATE

(e) Electron Multiplier

	ACTUAL
(1) Window #1 Bias	-1850 v
(2) Window #2 Bias	-2000 v

SIZE	CODE IDENT NO.	
A	26581	A-342269
SCALE		SHEET 6 of 11

F-135

(e) (Cont) ACTUAL

(3) First Dynode Bias (Positive) GND. 0 V

(4) Second Dynode Bias (Negative) -2000 V

6/28/70
STAMP/DATE

4. Measure the electron currents as follows:

ACTUAL

(a) With Electron Gun #1 operating

(1)	Anode #1	15μA	15×10^{-6} A
(2)	Electron Accelerator #1	41μA	41×10^{-6} A
(3)	Electron Focus #1-A		0 A
(4)	Electron Focus #1-B		0 A
(5)	Electron Accelerator #2		0 A
(6)	Anode #2		0 A
(7)	Repeller		0 A

6/28/70
STAMP/DATE

(b) With Electron Gun #2 operating

ACTUAL

(1)	Anode #2	15μA	15×10^{-6} A
(2)	Electron Accelerator #2	36μA	36×10^{-6} A
(3)	Electron Focus #2-A		0 A
(4)	Electron Focus #2-B		0 A
(5)	Electron Accelerator #1		0 A
(6)	Anode #1		0 A
(7)	Repeller		0 A

6/28/70
STAMP/DATE

SIZE	CODE IDENT NO.	
A	28501	A-342269

SHEET 7 of 13

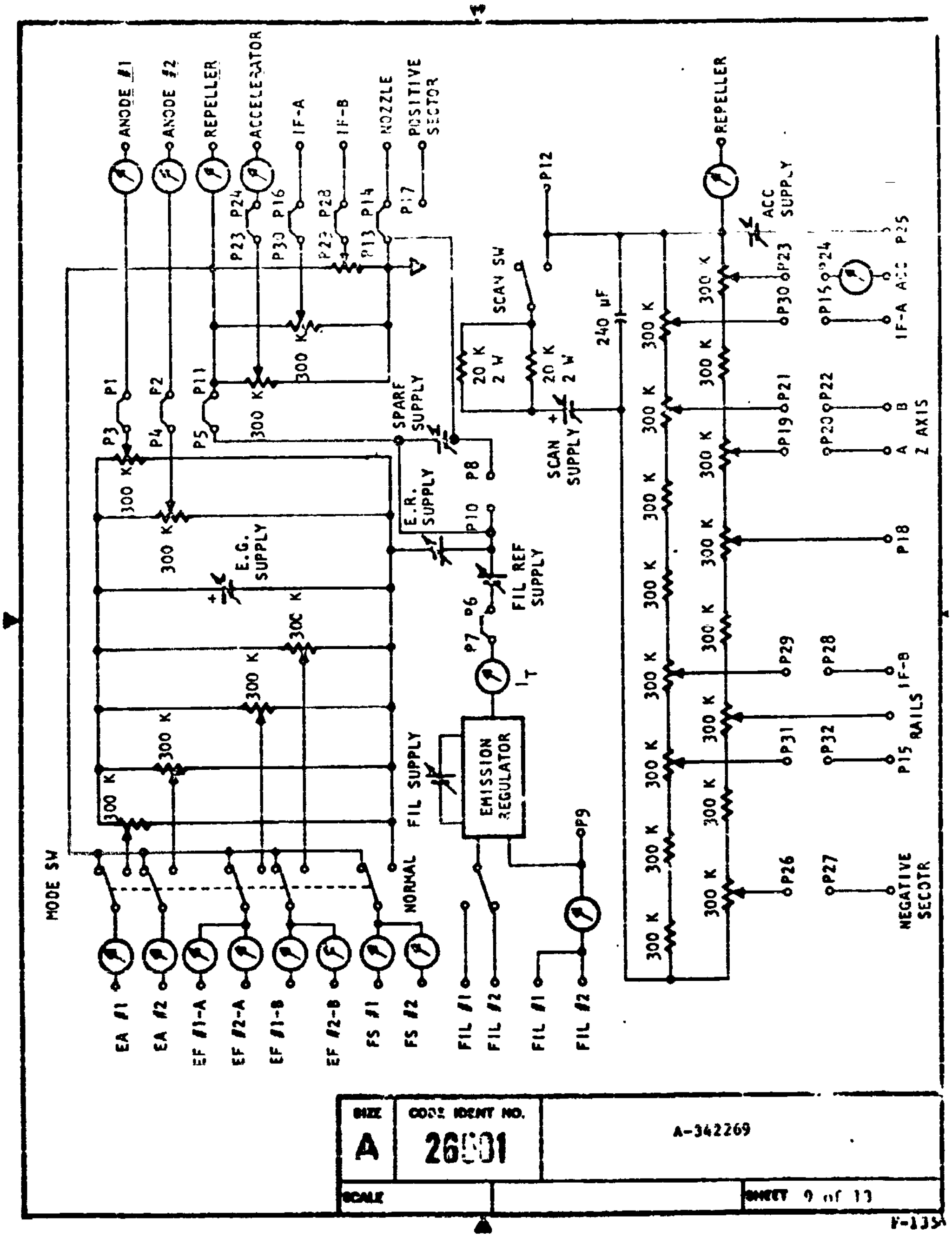
F-135A

5. **Filament Characteristics.** Measure the filament current and the voltage across both filaments, with all the electron gun electrodes connected to the repeller potential, and at a total emission collected of 250 microamperes. Record actual current and voltage measured on Test Data Sheet.

6. **Dynamic Range.** Measure the dynamic range from highest peak to lowest valley. Record data on Test Data Sheet. Vary the electron multiplier voltage, anode current no higher than 30 ± 2 microamps and pressure no higher than $2 \pm 1 \times 10^{-6}$ torr as required for maximum dynamic range or over 10^5.

SIZE	CODE IDENT NO.	
A	26501	A-342269
SCALE		SHEET 8 of 11

F-135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EA #1
EA #2
EF #1-A
EF #2-A
EF #1-B
EF #2-B
FS #1
FS #2
FIL #1
FIL #2
ANODE #1
ANODE #2
REPELLER
ACCELERATOR
IF-A
IF-B
NOZZLE
POSITIVE SECTOR
E.G. SUPPLY
E.R. SUPPLY
SPARE SUPPLY
FIL REF SUPPLY
FIL SUPPLY
EMISSION REGULATOR
SCAN SW
SCAN SUPPLY
ACC SUPPLY
240 μF
20 K 2 W
300 K
Z AXIS
RAILS
NEGATIVE SECOTR
SIZE
A
CODE IDENT NO.
A-342269
SCALE
SHEET 9 of 13

6. DATA SHEET

SERIAL NUMBER 0001

gel 6/28/70
STAMP/DATE

REF. PARA. 5 GUN #1

a. STEP

1(a) Record pressure level 4.8 x10^{-7} torr
ACTUAL

6/28/70
STAMP/DATE

(b) Current at first dynode 8.3 x10^{-13} A
ACTUAL

6/28/70
STAMP/DATE

Scan recorded on X-Y plotter Scan #1 6/28/70
STAMP/DATE

(c) Record pressure level 1.7x10^{-6} torr
ACTUAL

6/28/70
STAMP/DATE

(d) Current at first dynode 9.5x10^{-13} A
ACTUAL

6/28/70
STAMP/DATE

Scan recorded on X-Y plotter Scan #2 6/28/70
STAMP/DATE

Note: Anode current = 15 mA

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20501	A-342269
SCALE		SHEET 10 of 13

F-13

6. DATA SHEET (Cont)

SERIAL NUMBER 0001

6/28/70 STAMP/DATE

REF. PARA. 5   GUN #2

a. STEP

1(e) Record pressure level — 4.5 x 10^-7 torr ACTUAL

9/28/70 STAMP/DATE

Current at first dynode — 9.0 x 10^-13 A ACTUAL

6/28/70 STAMP/DATE

Scan recorded on X-Y plotter — Scan #3 — 6/28/70 STAMP/DATE

Record pressure level — 2.0 x 10^-6 torr ACTUAL

6/28/70 STAMP/DATE

Current at first dynode — 1.04 x 10^-12 A

6/28/70 STAMP/DATE

Scan recorded on X-Y plotter — Scan #4 — 6/28/70 STAMP/DATE

(f) Calculated ion source sensitivity — #1 1.0 x 10^-7 amps/torr ACTUAL

#2 9.04 x 10^-8 amp/torr ACTUAL

Emission current (Anode) — 15 x 10^-6 A ACTUAL

Note: Anode current is 15 μA

6/28/70 STAMP/DATE

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20581	A-342269
SCALE		SHEET 11 of 11

F-135

6. DATA SHEET (Cont)

SERIAL NUMBER 0001 — 6/28/70 STAMP/DATE

REF. PARA. 5 Scan 5 ran here JSE

a. STEP

2(a) Peak ~~scanned on X-Y plotter~~ or measured on Keithley. JSE — 6/28/70 STAMP/DATE

(b) Calculated gain from peak top (m/e 28)

2nd Aperture Voltage		Keithley Readings	
-1445	-1500 Vdc	1.08×10^{-8} Amps	5.96×10^{4} ACTUAL
-1750	-1750 Vdc	4.3×10^{-8} Amps	2.38×10^{5} ACTUAL
-2050	-2000 Vdc	1.55×10^{-7} Amps	8.56×10^{5} ACTUAL
-2300	-2250 Vdc	4.4×10^{-7} Amps	2.43×10^{6} ACTUAL
-2500	-2500 Vdc	1.0×10^{-6} Amps	5.52×10^{6} ACTUAL

JSE 6/28/70 STAMP/DATE

(d) Peak resolution should exceed $m/m = 1/40$

$\Delta m/m = \frac{1}{7.5} \frac{B}{S}$ SCAN 6 JSE — 1/42.9 ACTUAL — 6/28/70 STAMP/DATE

5. Filament #1

Voltage (filament power supply) — 3.60 V ACTUAL

Current — 1.30 A ACTUAL

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20501	A-342269
SCALE		SHEET 12 of 13

F-135

6. DATA SHEET (Concluded)

SERIAL NUMBER 0001

6/28/70
STAMP/DATE

REF. PARA. 5

a. STEP

5. (Cont)

Filament #2 (filament power supply)

Voltage 3.60 V

Current 1.32 A

Total emission collected (250 μA) 250 μA

6/28/70
STAMP/DATE

6. Dynamic range from highest peak to lowest valley SCAN 8

greater than 10^6
ACTUAL

6/28/70
STAMP/DATE

7.) VDC +46.0
WITH QUAD BIAS OFF -33.0

1) Test Conducted By 6-28-70

2) TEST WITNESSED BY, AND Data Verified By & RECORDED Jimmy E. Cooley NASA/GSFC 6/28/70

3) Concurrence By
DCAS QAR

ACCEPTANCE TEST PROCEDURE FOR MARTIAN QUADRUPOLE

SIZE	CODE IDENT NO.	
A	20581	A-342269
SCALE		SHEET 13 of 13

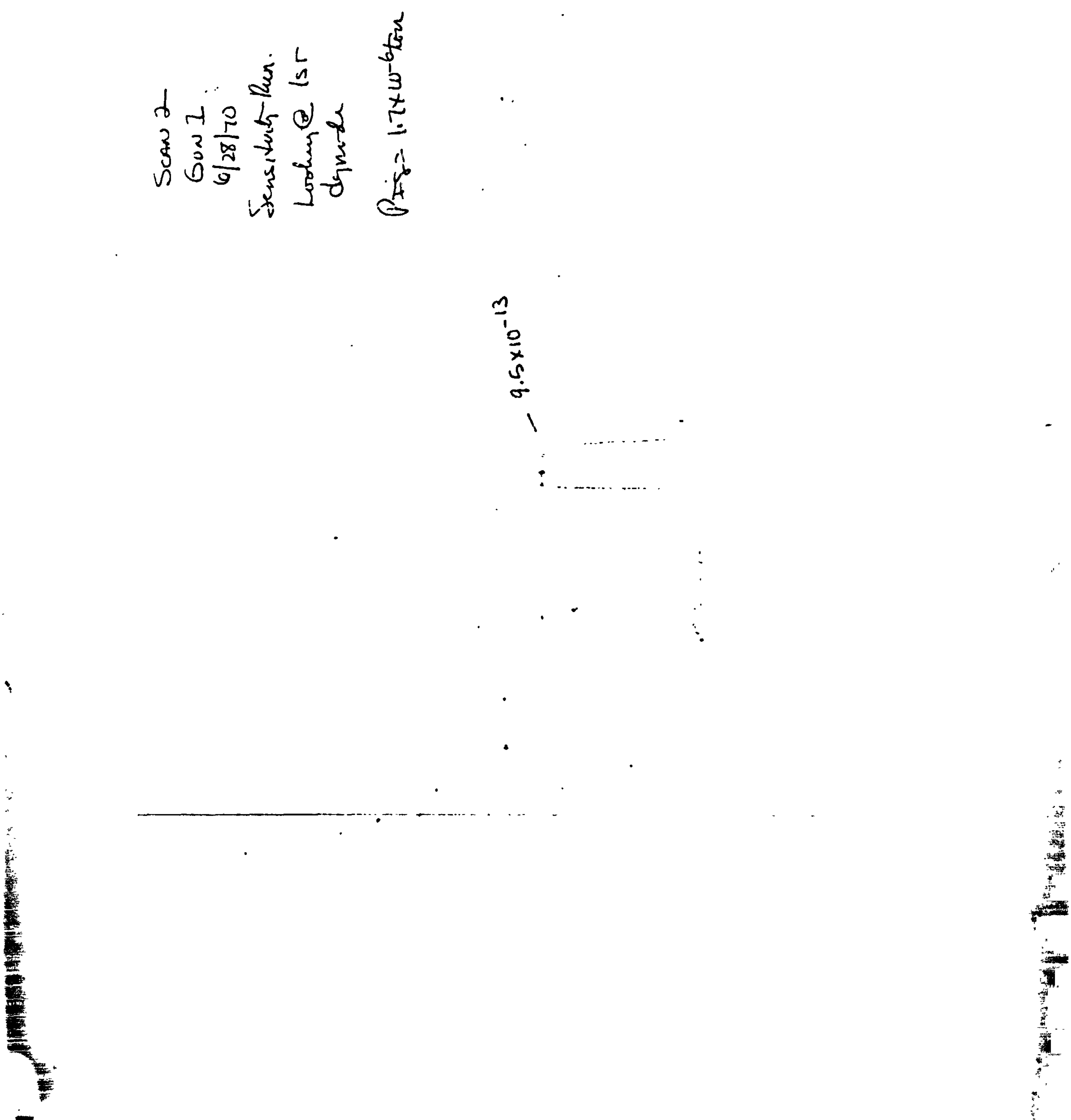
F-135A

Scan 1
Gun 1
6/28/70
Sensitivity Run
Looking @ 1st
dynode
$P_{IG} = 4.8 \times 10^{-7}$ torr

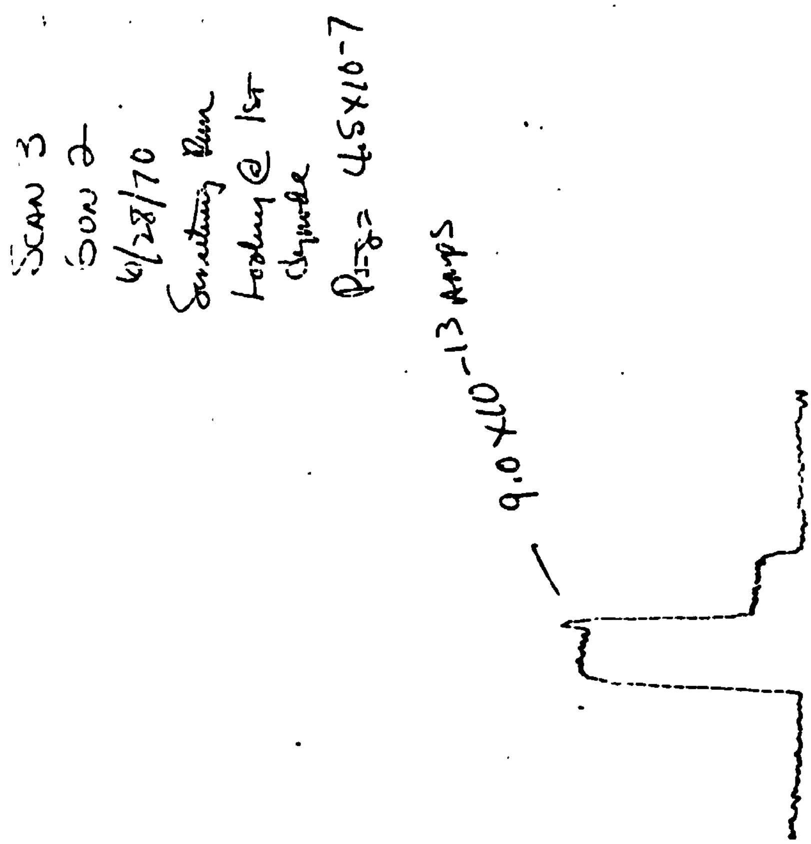
$$S_{gun\,1} = \frac{1.7\times10^{-6} - 4.8\times10^{-7}}{9.5\times10^{-13} - 8.3\times10^{-13}} = \frac{1.22\times10^{-6}}{1.2\times10^{-13}}$$

$$S_{gun\,1} = 1.00\times10^{-7}\ \frac{\text{Amps}}{\text{Torr}}$$

APPENDIX C


Scan 2
Gun I
6/28/70
Sensitivity Run.
Looking @ 1st
dynode
P = 1.74×10⁻⁶ torr
9.5x10⁻¹³

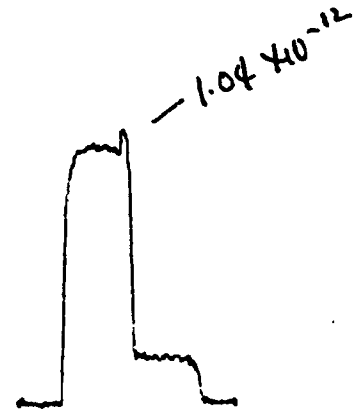
APPENDIX C



SCAN 4
GUN 2
6/28/70
Sensitivity Run
Looking @ 1CF
Oxymode
$P_{IG} = 2 \times 10^{-6}$

$$S_{gm_2} = \frac{1.04 \times 10^{-12} - 9 \times 10^{-13}}{2 \times 10^{-6} - 4.5 \times 10^{-7}} = \frac{1.4 \times 10^{-13}}{1.55 \times 10^{-6}}$$

$$S_{gm_2} = 9.04 \times 10^{-8} \text{ Amp./TORR}$$



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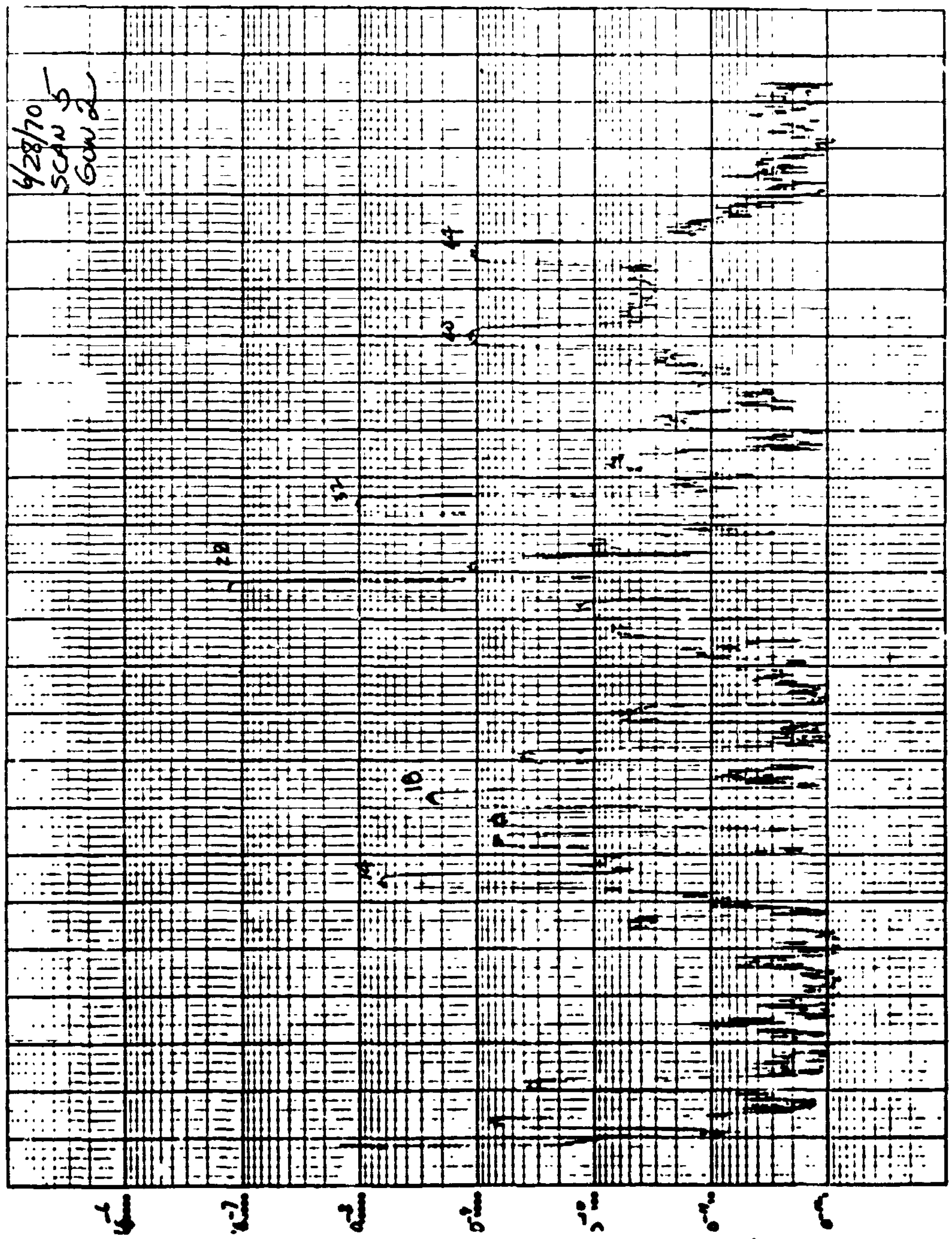

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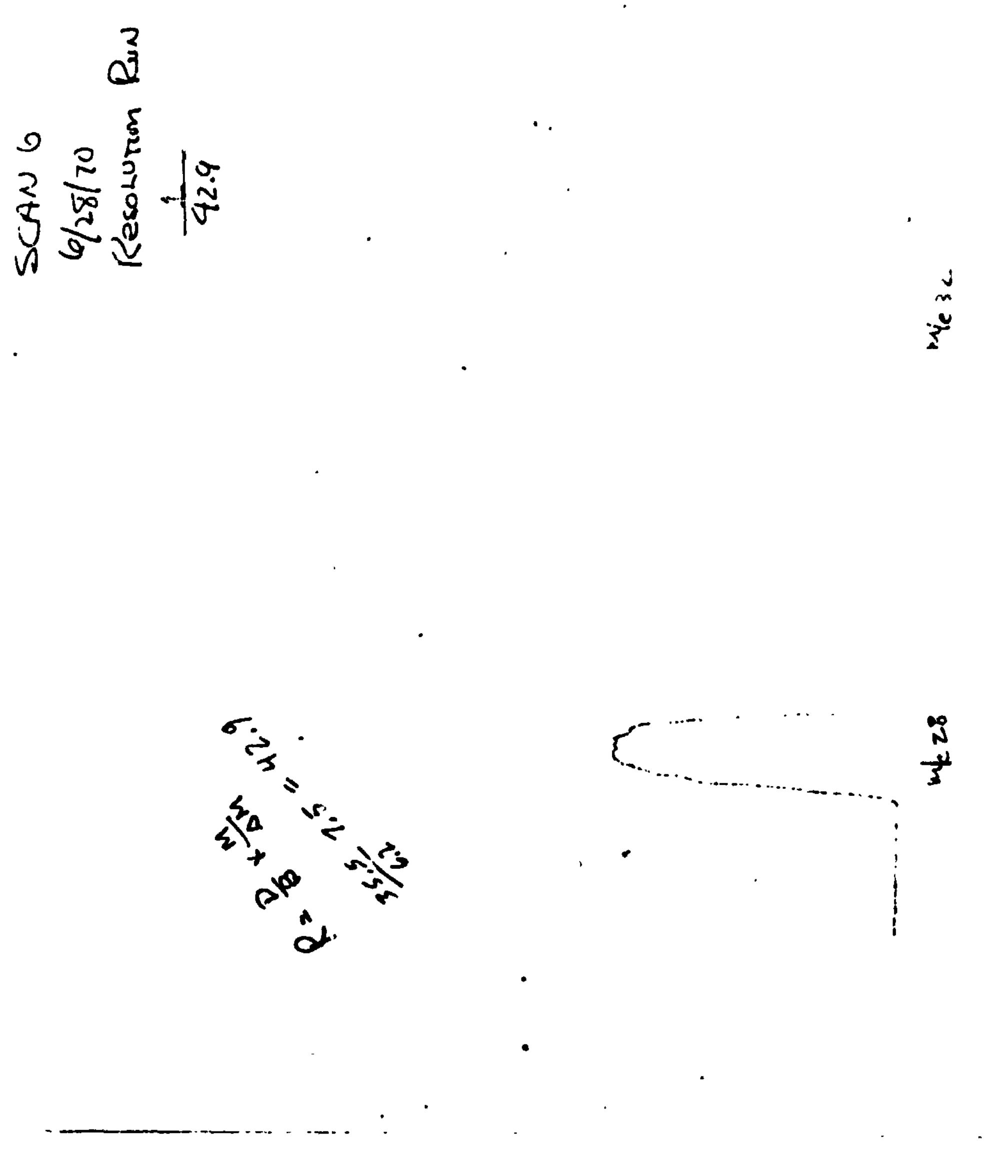

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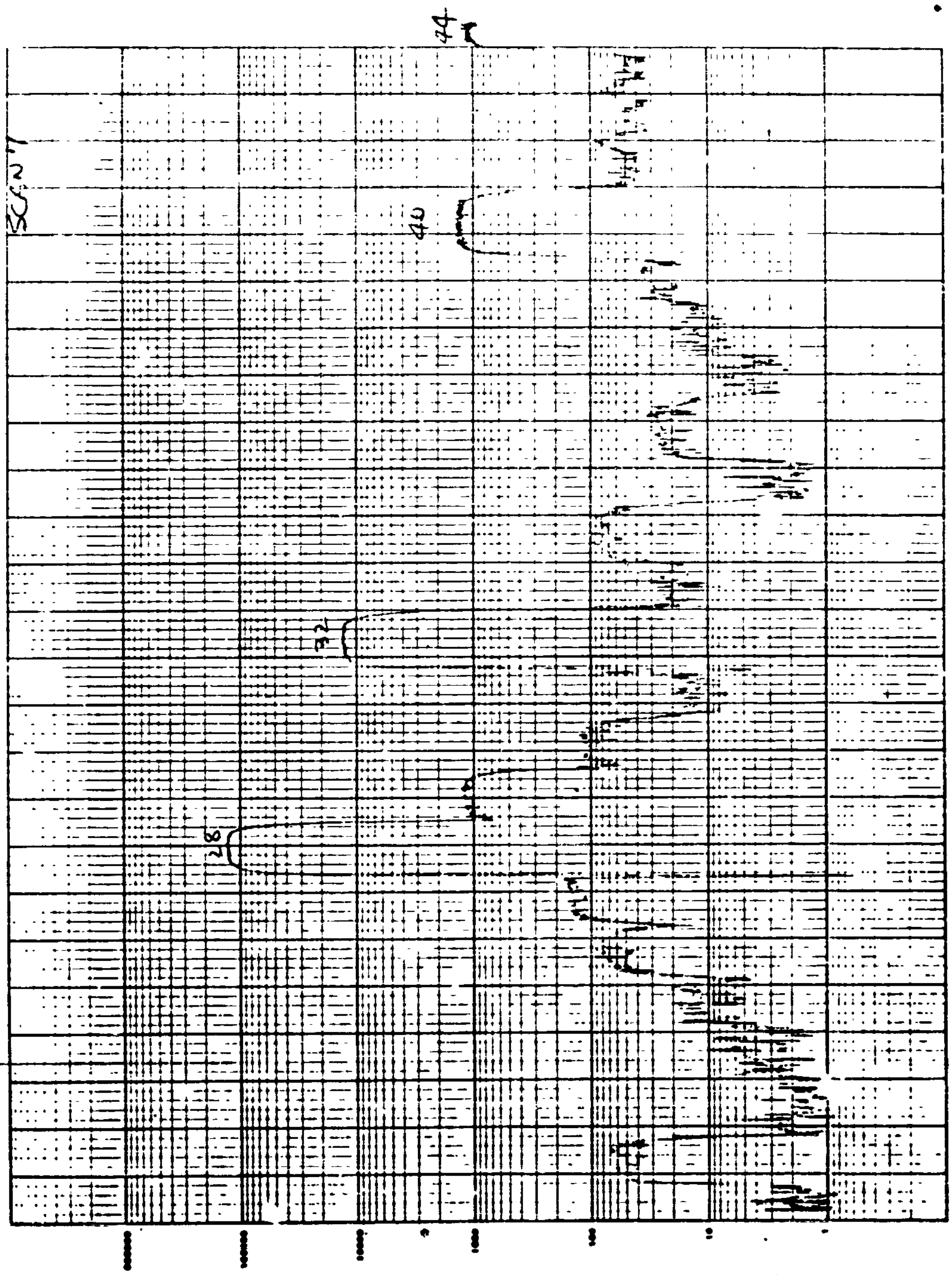
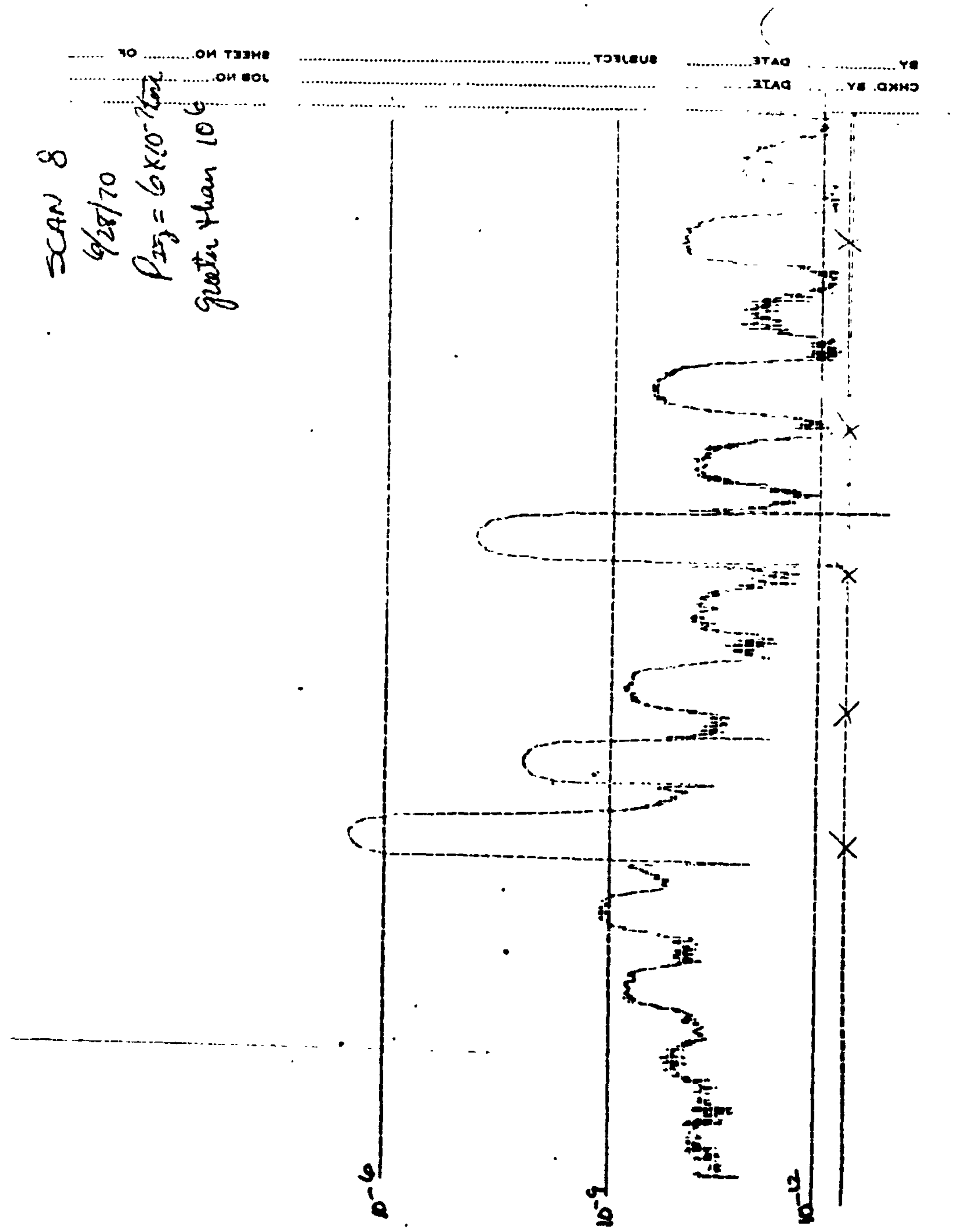



SCAN 8
6/28/70
10^-6
10^-9
10^-12

APPENDIX C

NONCONFORMANCE REPORT

PERKIN ELMER AEROSPACE SYSTEMS
Pomona, California

JOB NO.	PAGE NO	ITEM NO	NO	PAGE OF
30001	(1) 1	7	6182	

P/O	ITEM	QTY REC	QTY INSP	QTY REJ	PART NO	REV
12871 M	1	1	1	1	341880	

VENDOR	PROJECT CUSTOMER	PART NAME
ELECTRON BEAM WELDING	NASA - GSFC	QUAD ANALIZER ASSY

MO DAY YR	T.W.O. NO	CONTRACT NO.	INSPECTION CRITERIA
6 24 70		NAS 5-11185	☒ DWG ☐ SPEC ☐ TEST ☐ OTHER

DISCREPANCY

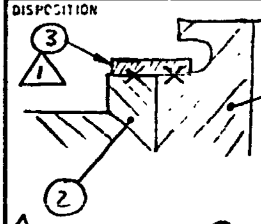
LOT 061 SERIAL NO. 0001

BELLOWS FLANGE SPOT WELD TO END PLATE IS BROKEN LOOSE.

INSP IDENT	DATE	INSP SUPERVISOR	DATE	RESPONSIBILITY	FREQ
Emerwin	6/24	J. Wild	6/24/70		

DISPOSITION

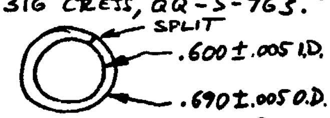
ENGR. REVIEW ☒ MRB ☐



① ADAPTOR, BELLOWS 341877

② HOUSING 341894

③ WELD RING, MAT'L .01 THK, 316 CRESS, QQ-S-763.



△1 TACK WELD ③ TO ① & ②
APPROX. EVERY .1 AS SHOWN.
WELD SCHEDULE:
ELECTRODE: RWMA 2
PRESSURE: 5 LBS
POWER: 60 WATT SEC

QTY USE AS IS:
QTY RTS:
QTY REWORK: PER ECO 25696
QTY SCRAP:
QTY SALVAGE:
RE-INSPECTED QTY: 1
STAMP

ENGR REP	DATE	Q.A. REP	DATE	CUST GOVT REP	DATE	REWORK INSP	DATE
[signature]	6/24/70	[signature]	6-24-70	N/R		☒ ACC ☐ NOT ACC	6/24/70

CORRECTIVE ACTION — NAME AND DATE

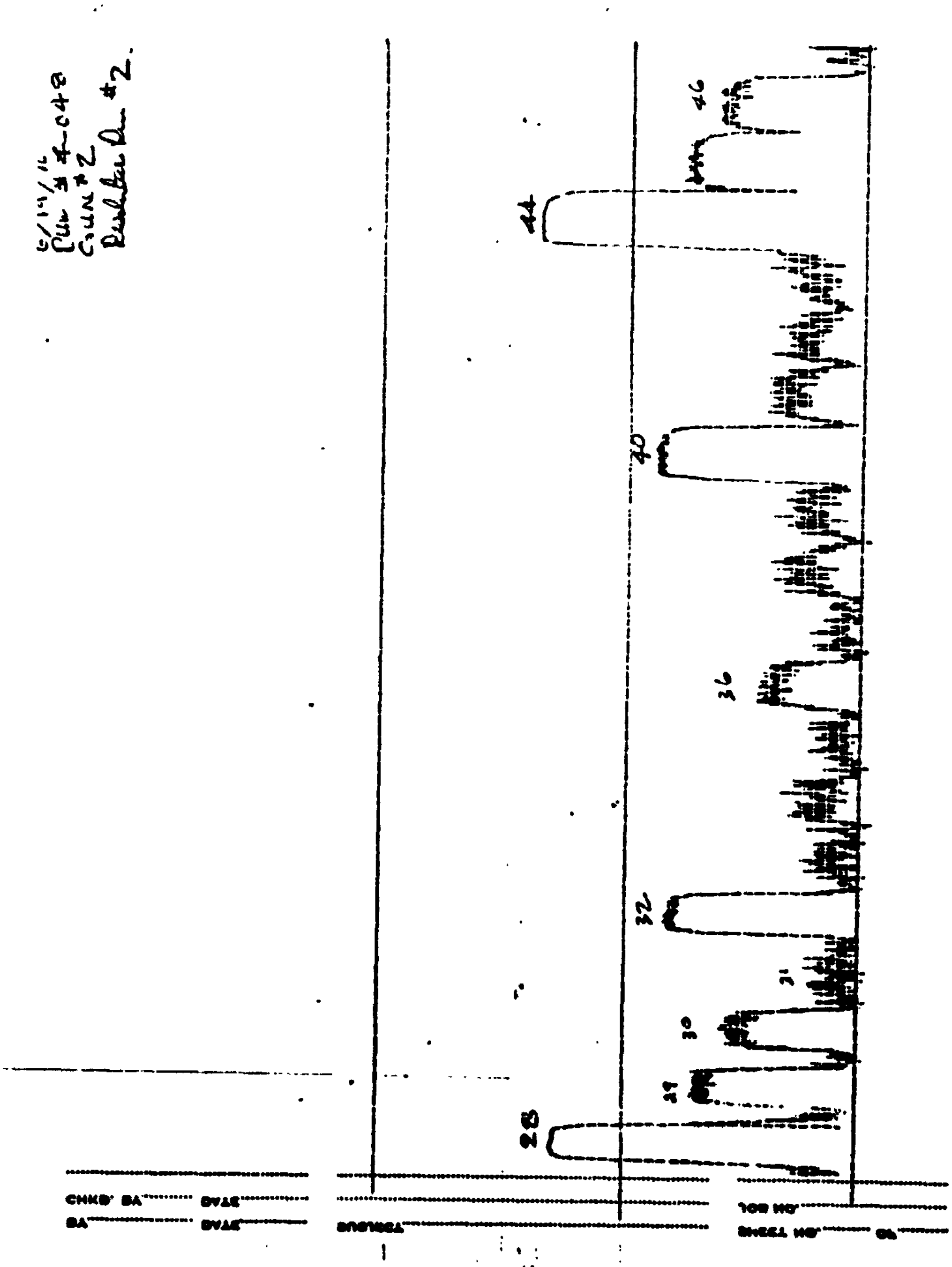
N/A THIS IS THE FINAL UNIT OF THE CONTRACT AND THIS DESIGN WILL NOT BE PRODUCED AGAIN.
THE PRIOR WELDMENTS WERE BROKEN DURING IMPROPER ATTEMPT TO SEAL THE INLET FOR LEAK TESTING ENCLOSURE. [signature]

PURCHASING MATERIAL CONTROL ACTION — SIGN AND DATE

REQUIRED RETURN DATE

DISTRIBUTION: WHITE - QA YELLOW - INSPECTION PINK - PURCHASING GREEN - MAT'L CONT MANILLA - ATTACH TO MATERIAL

APPENDIX C



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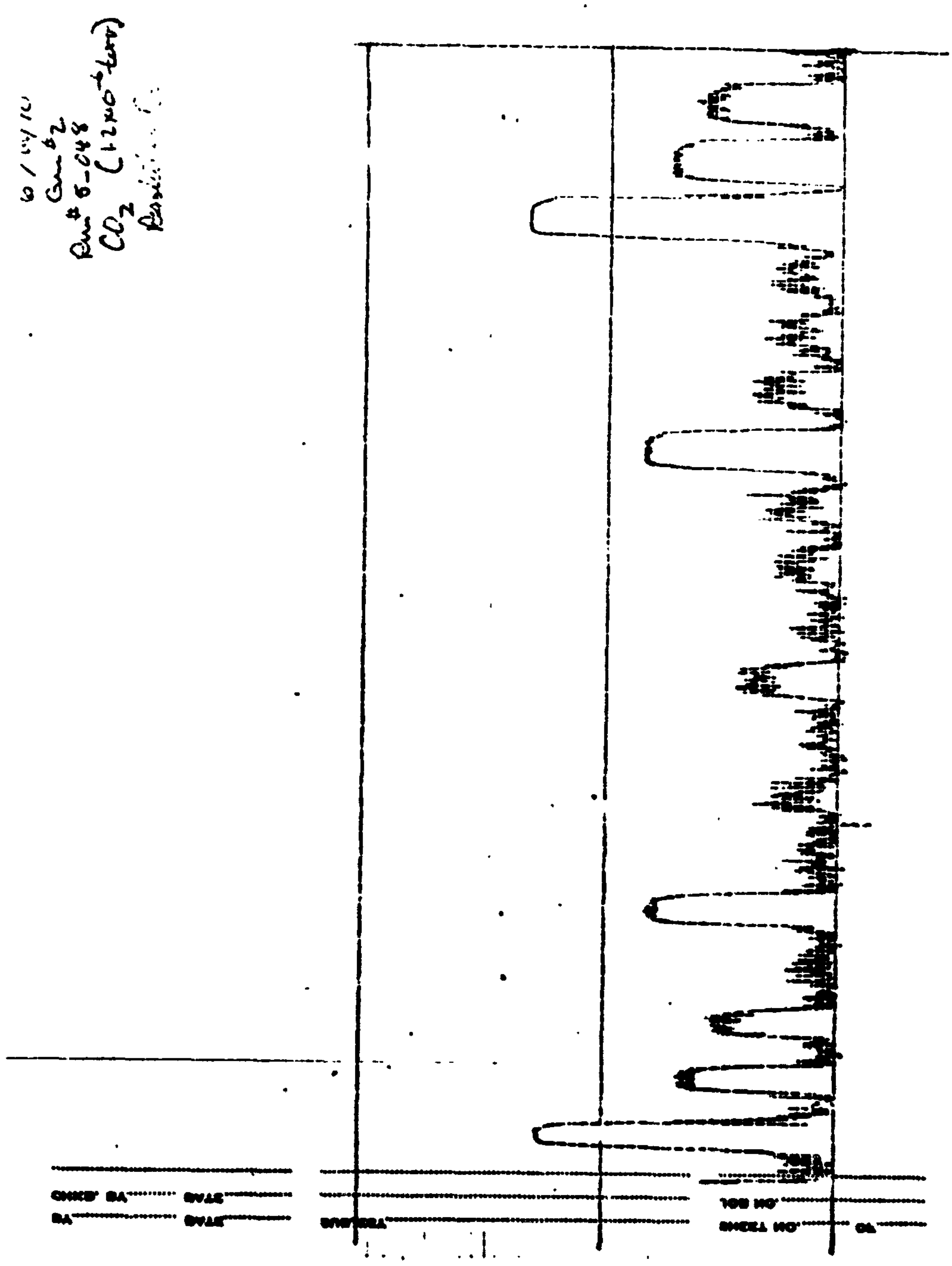

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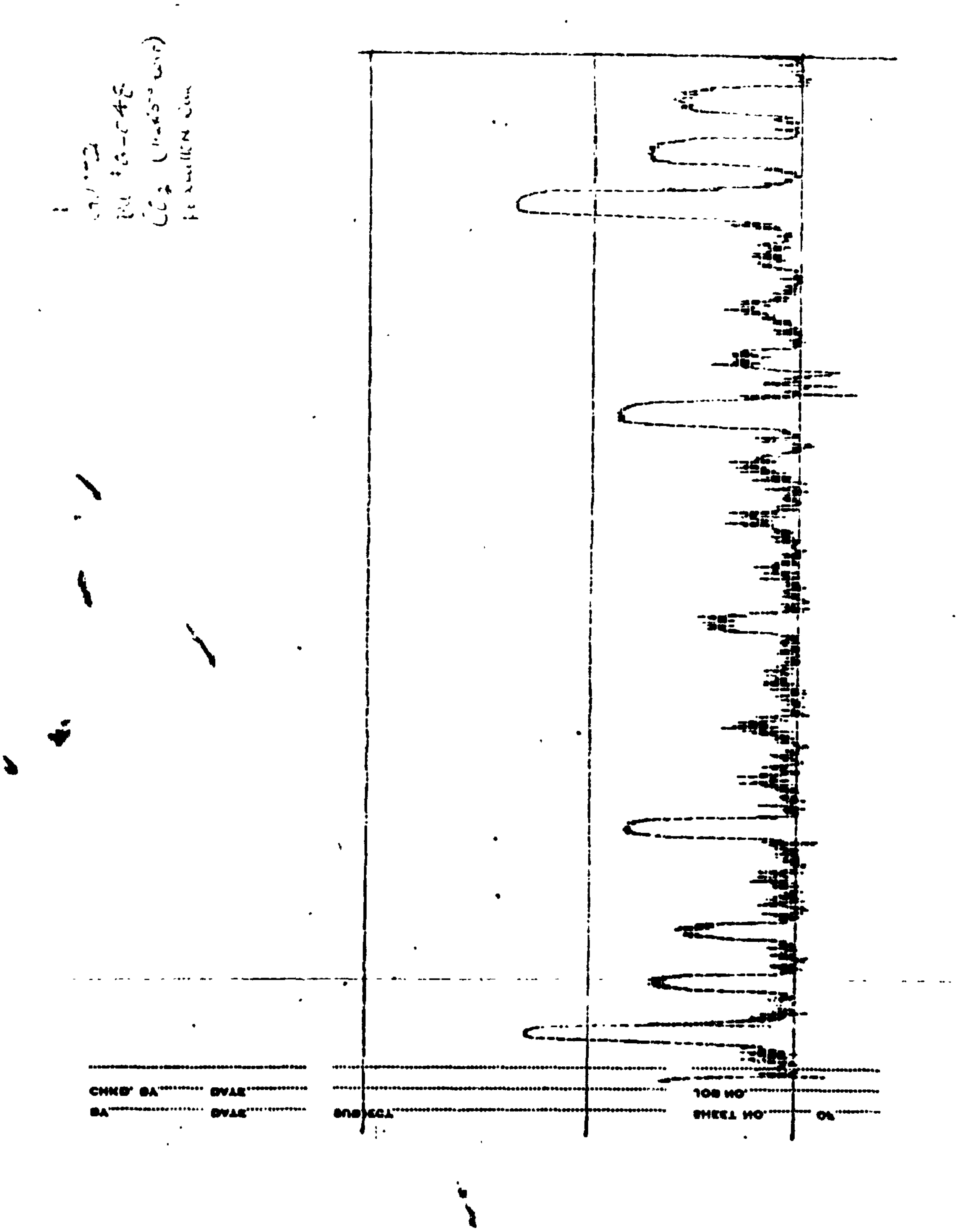

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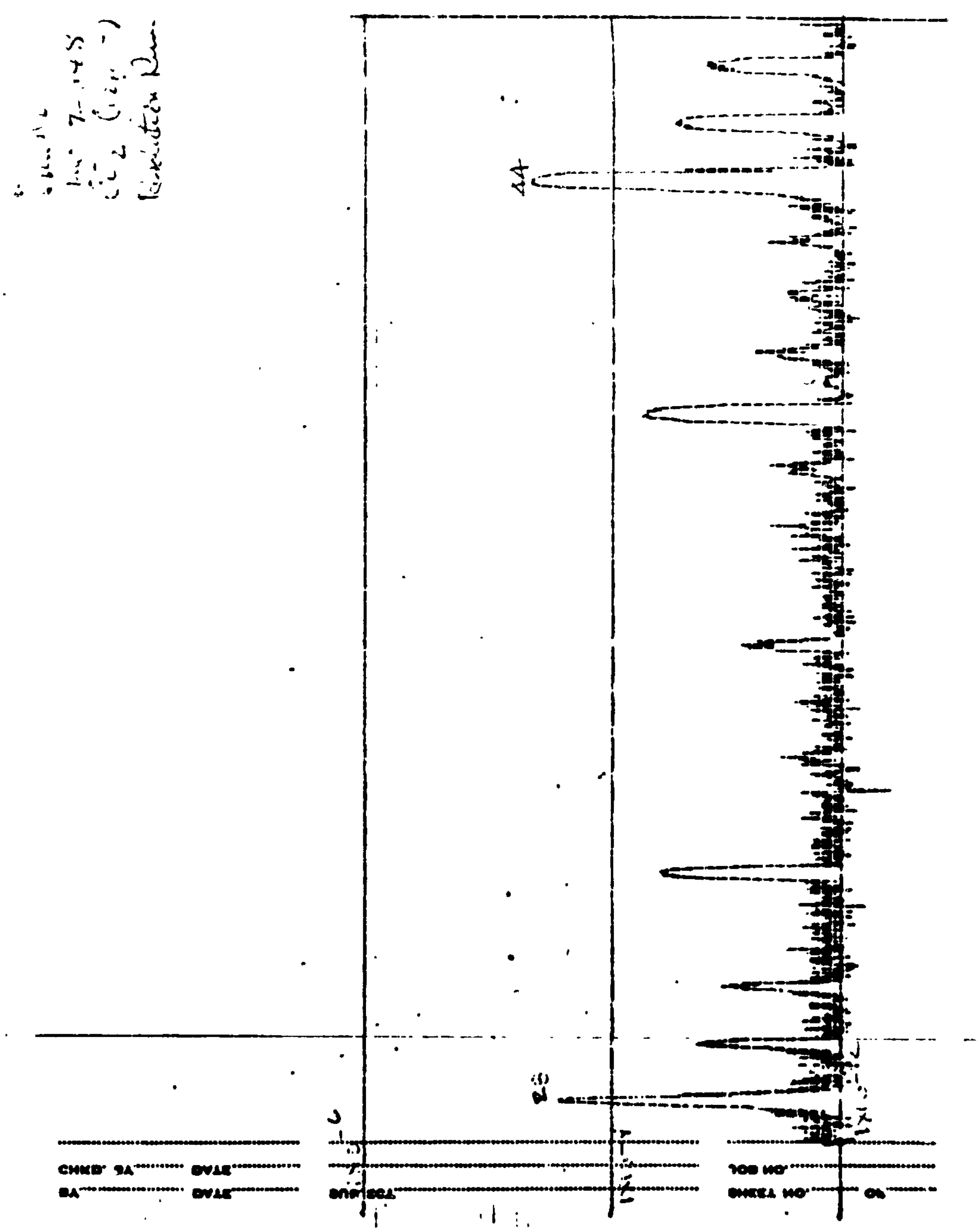

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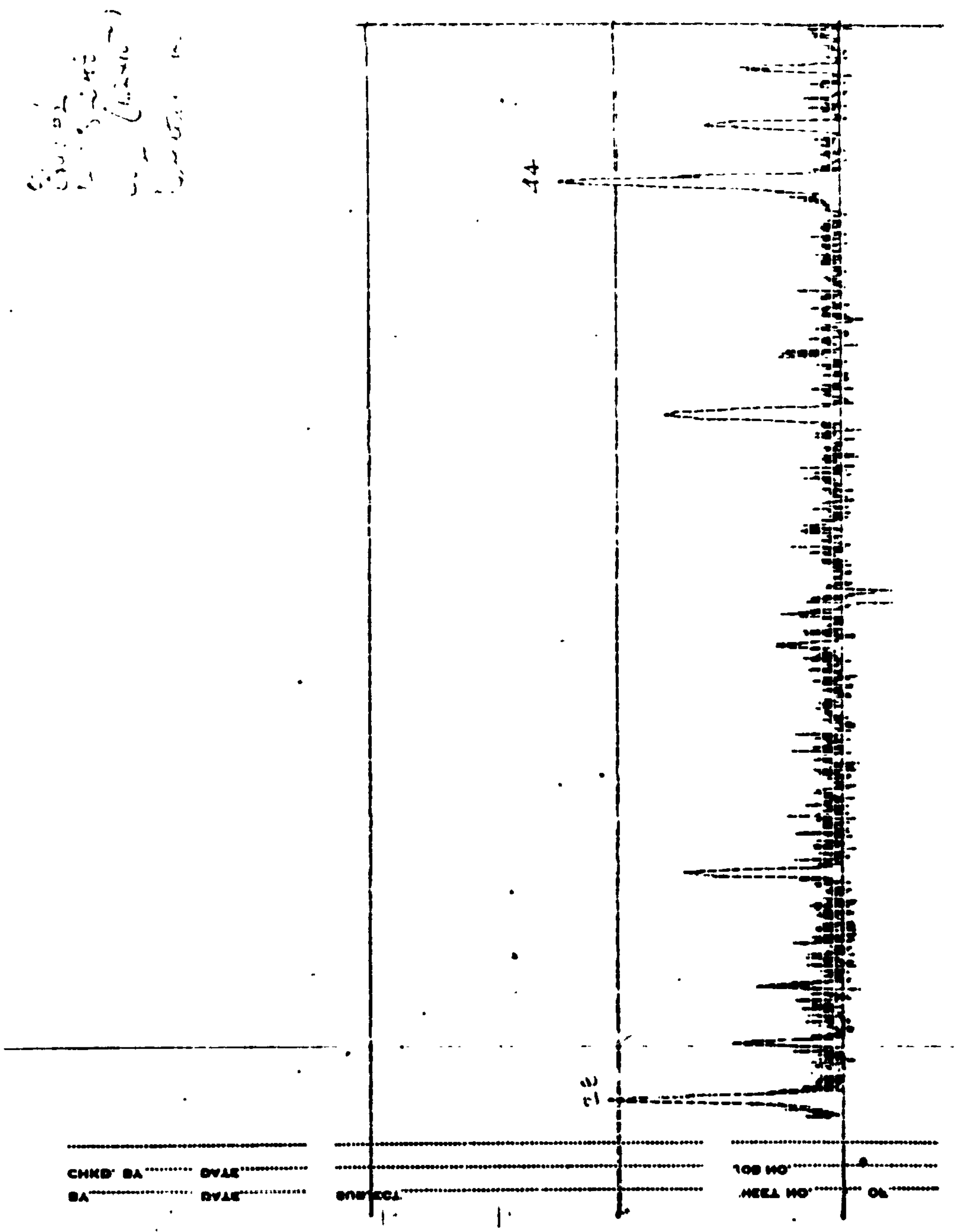

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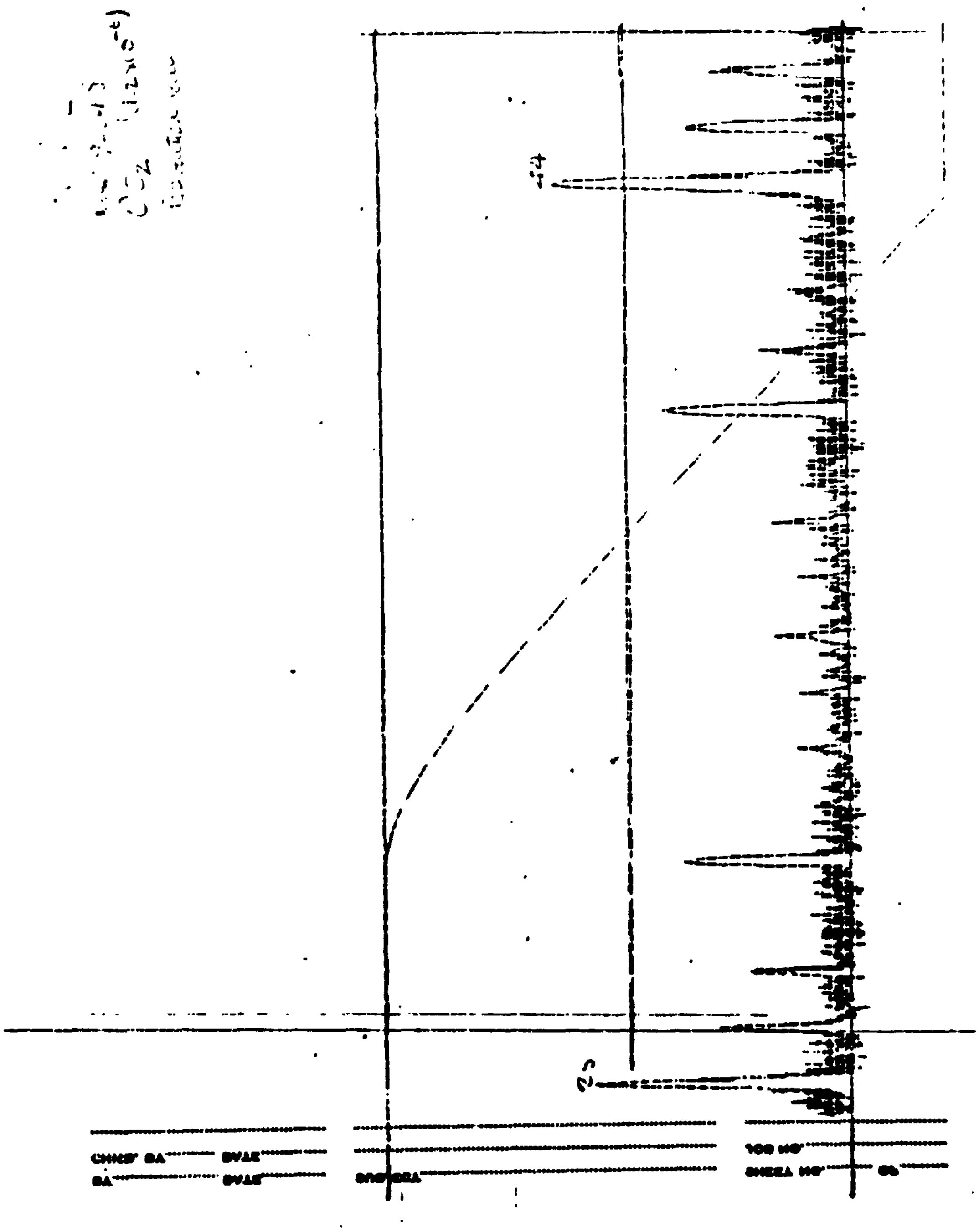

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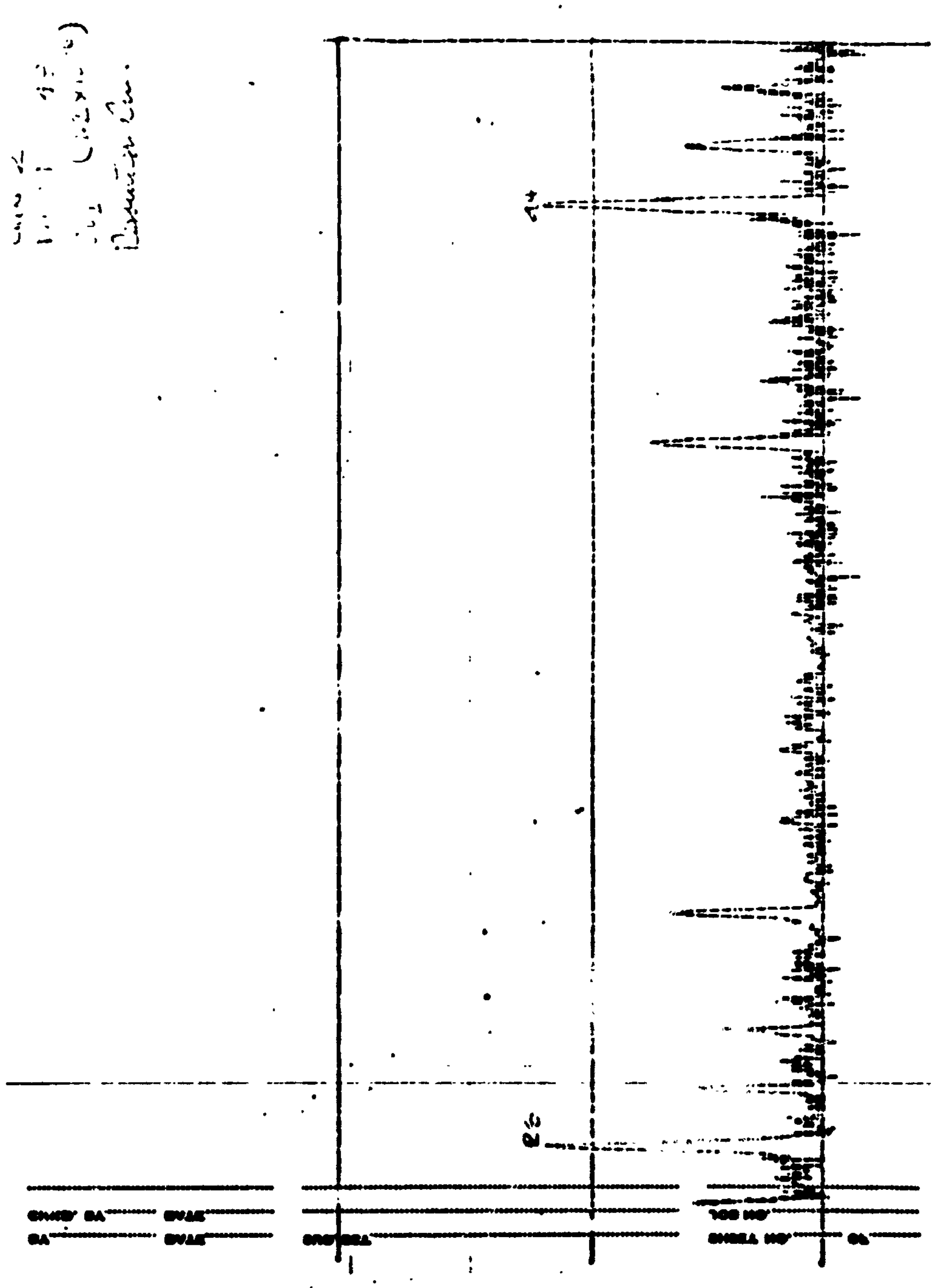

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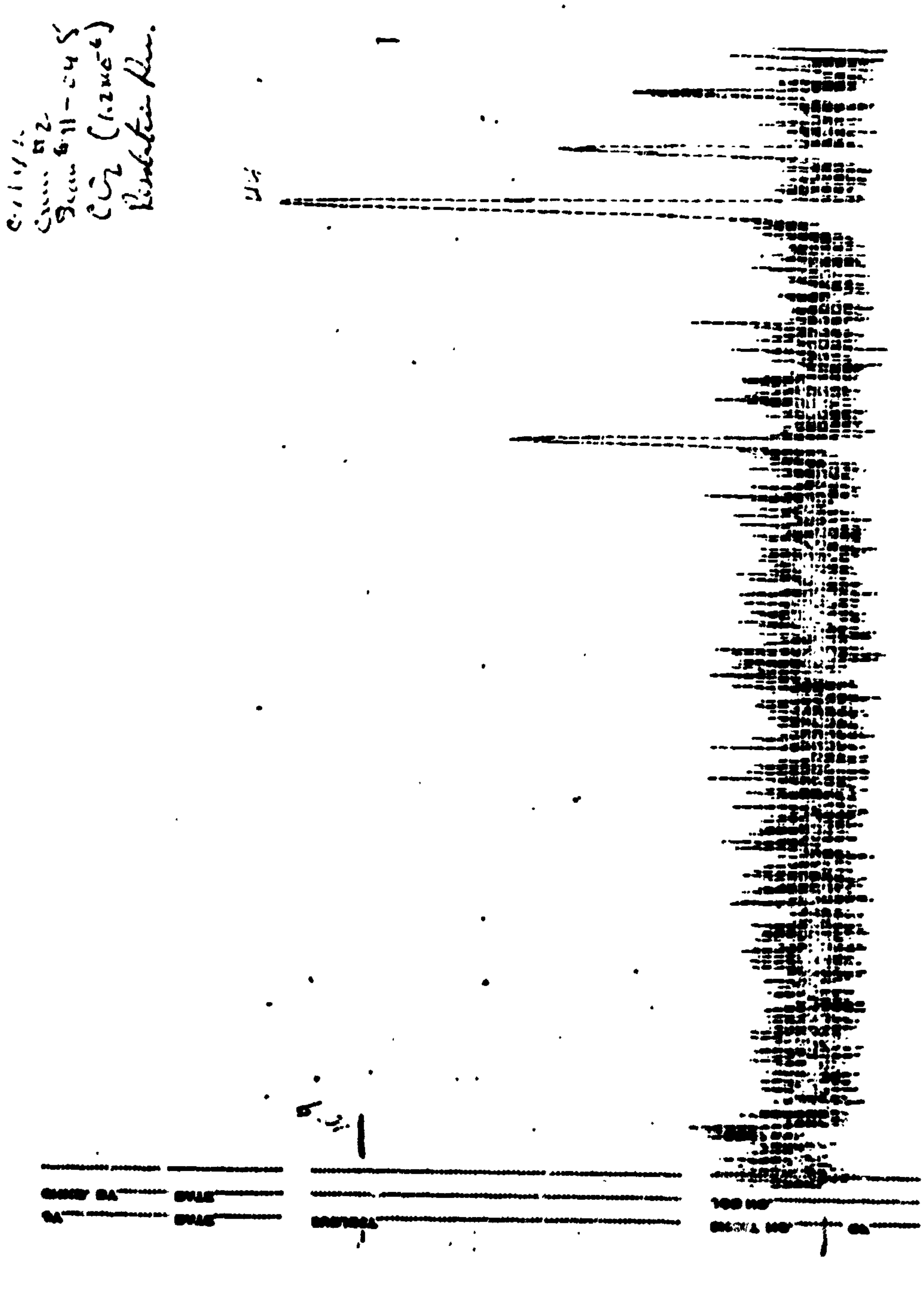

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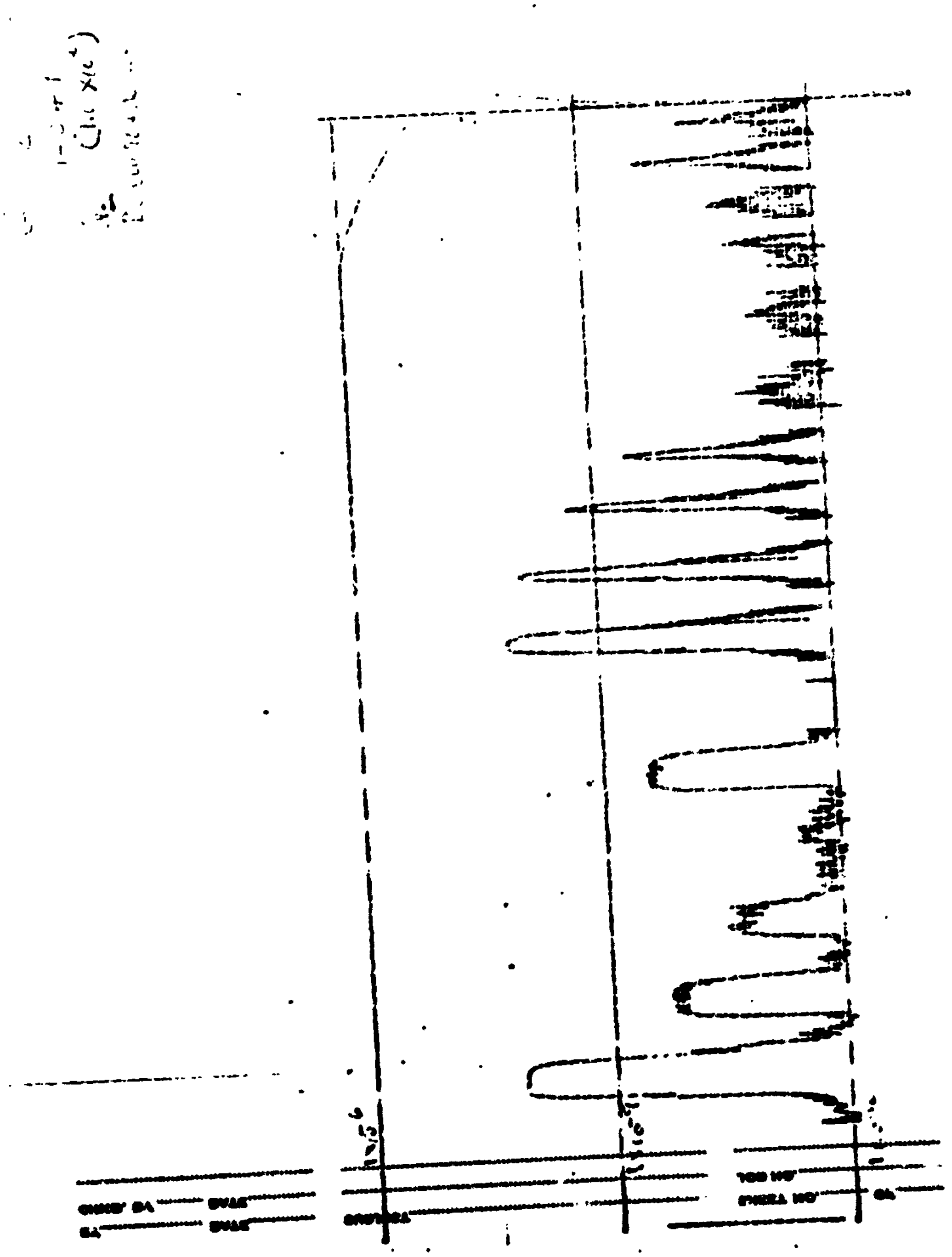

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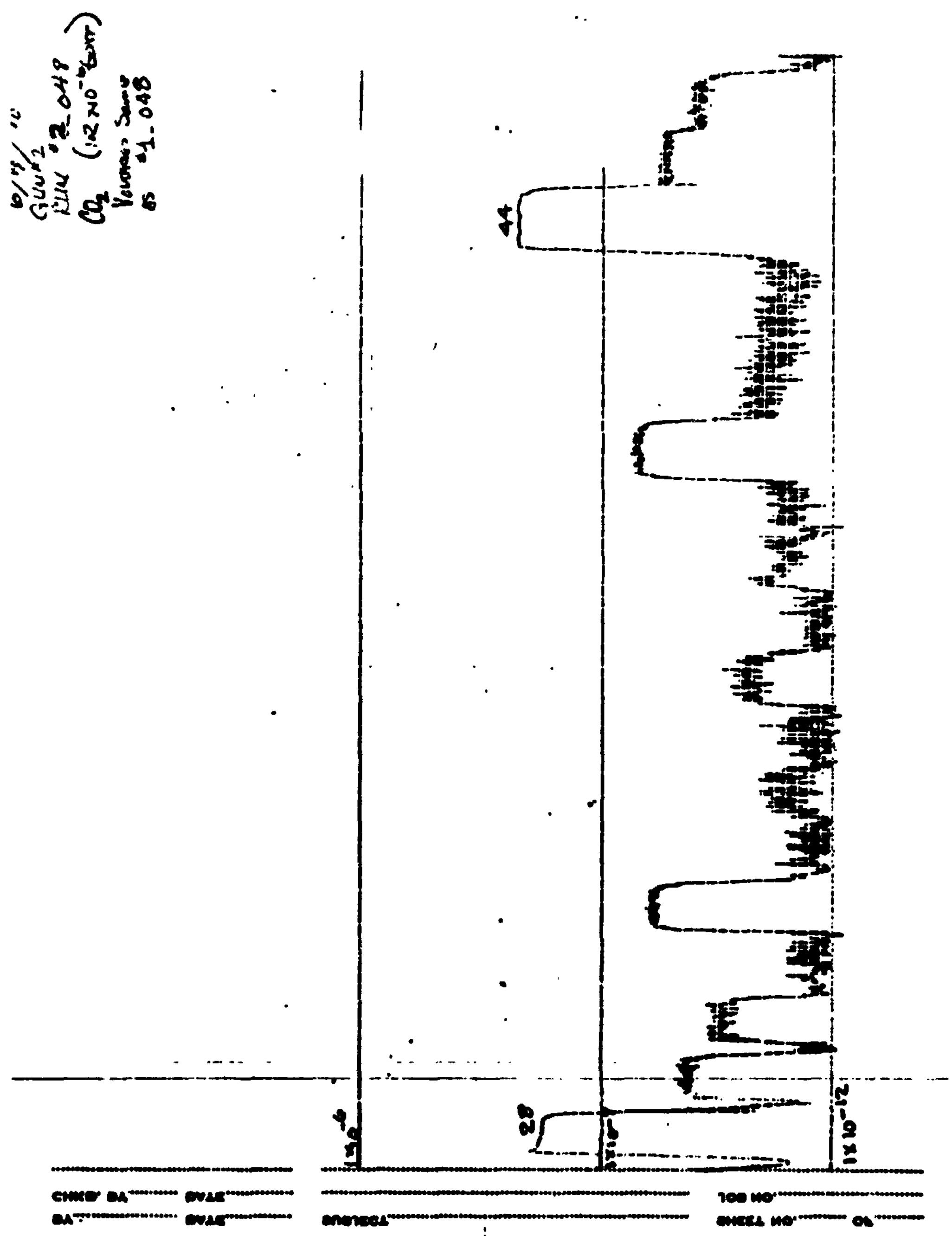

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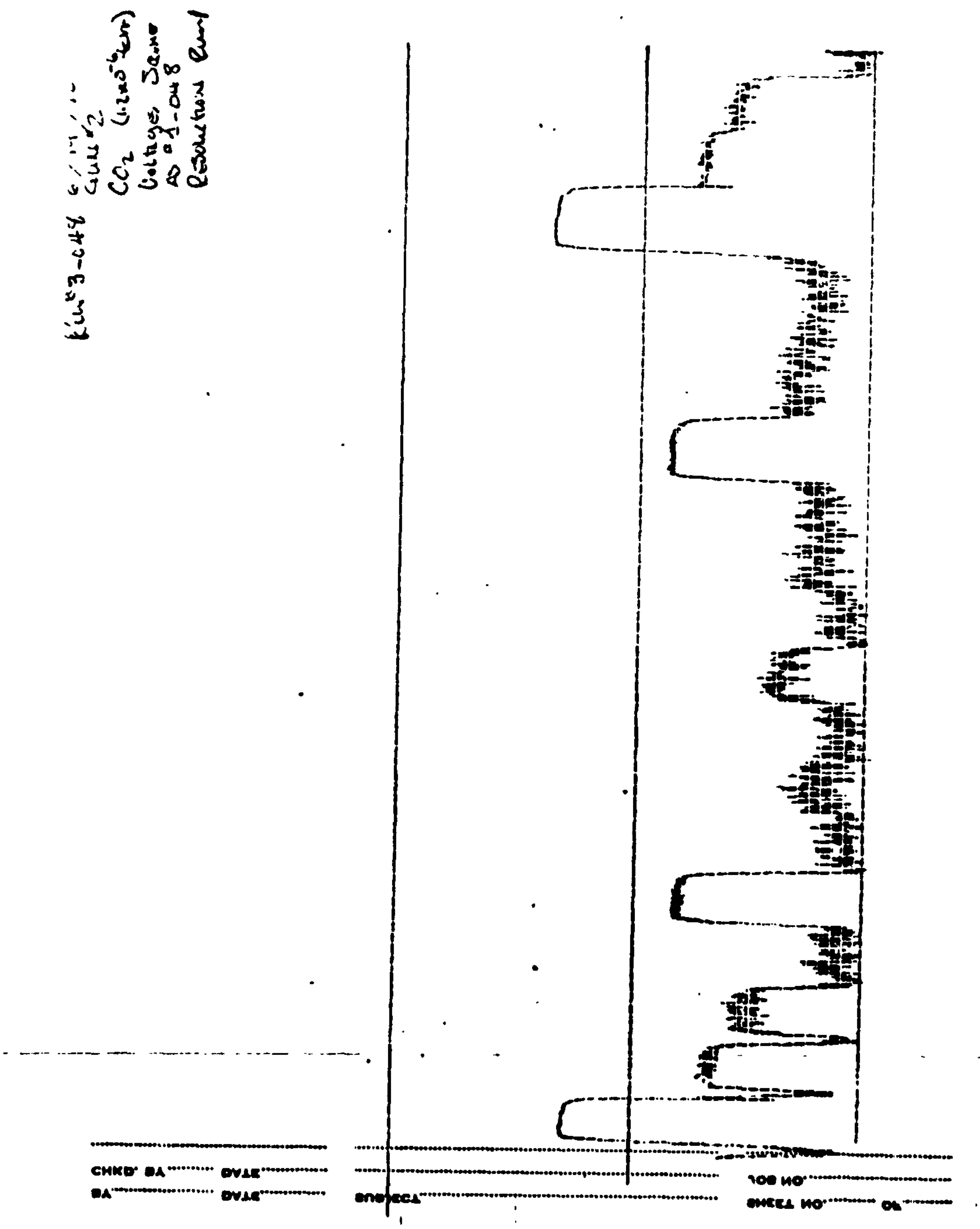

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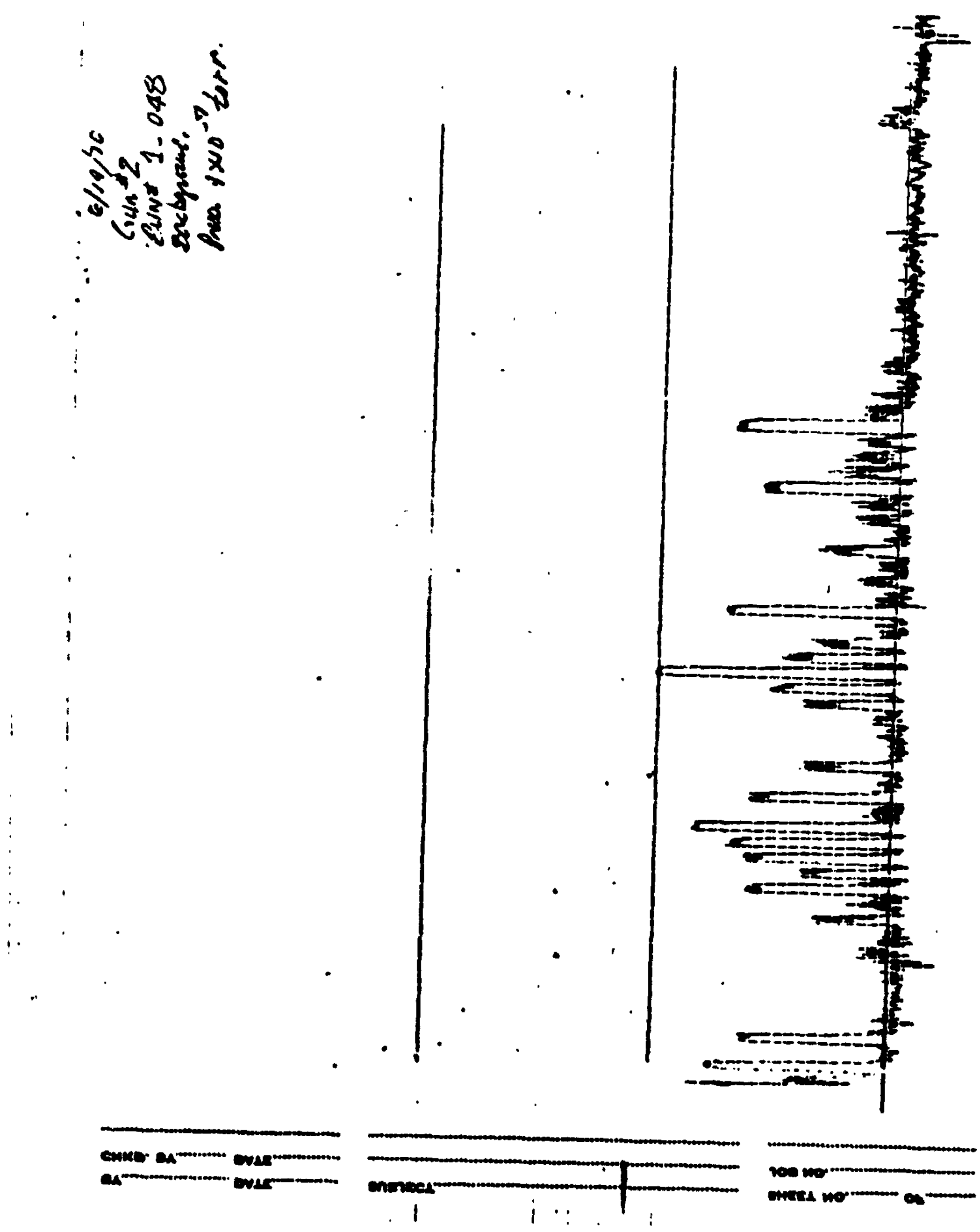

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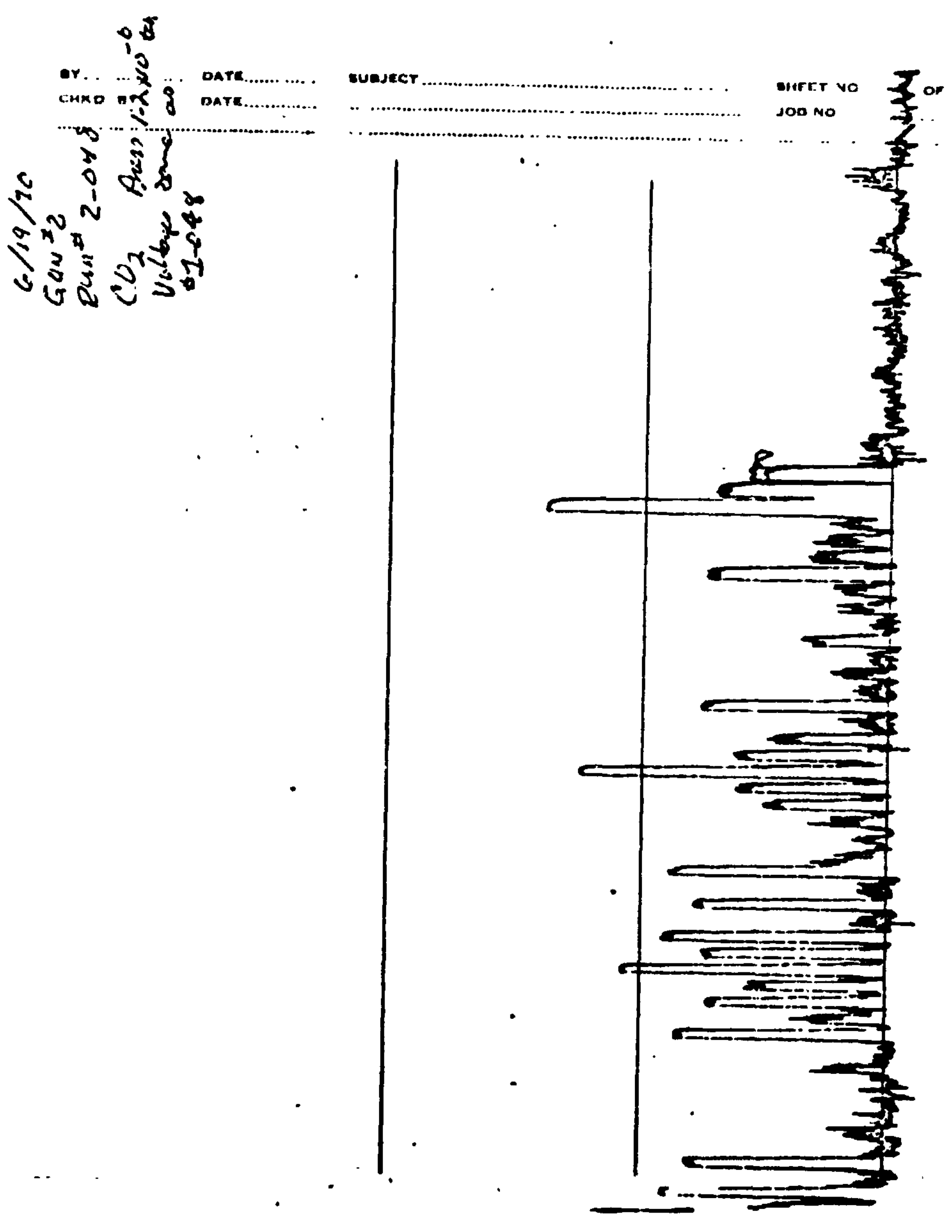

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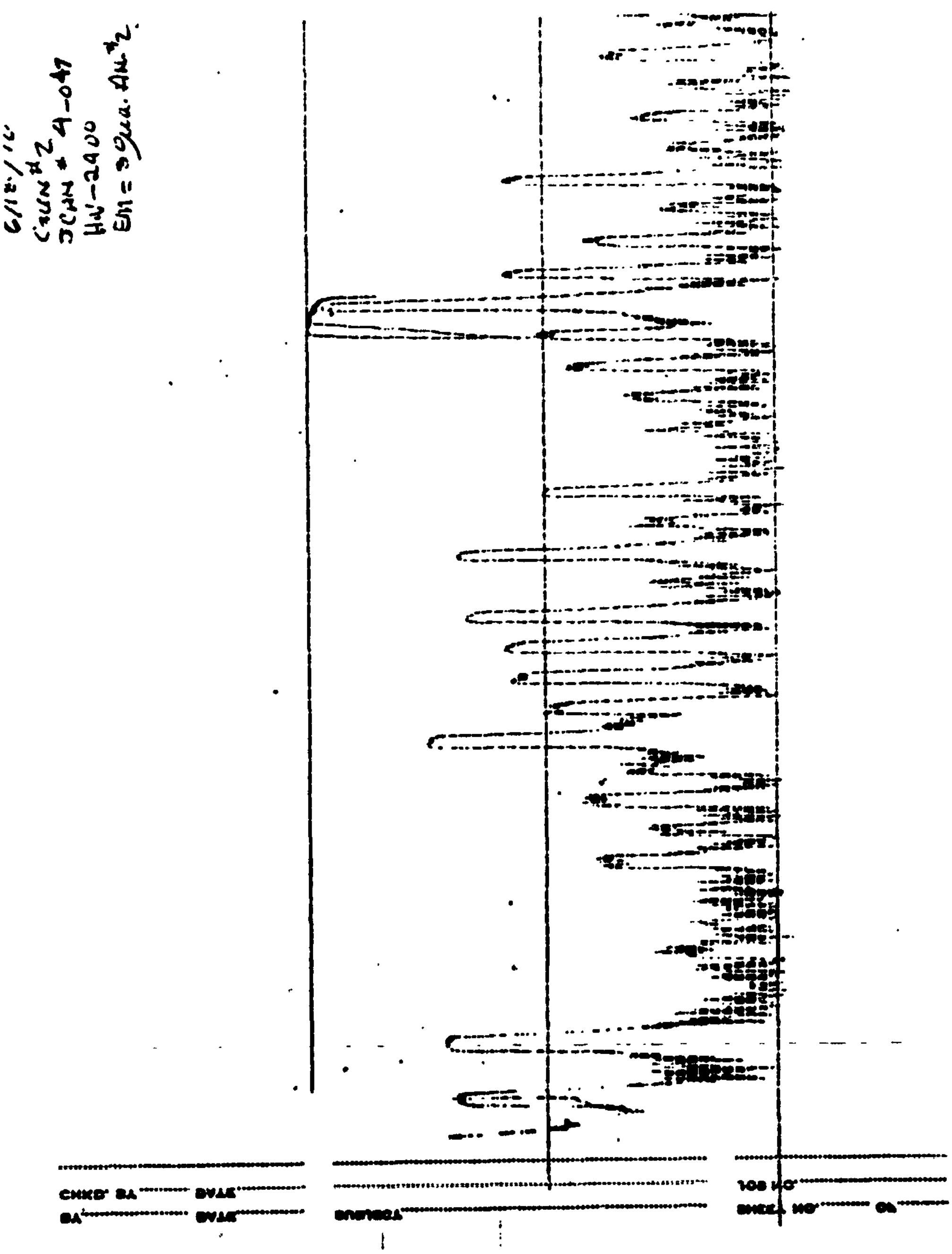

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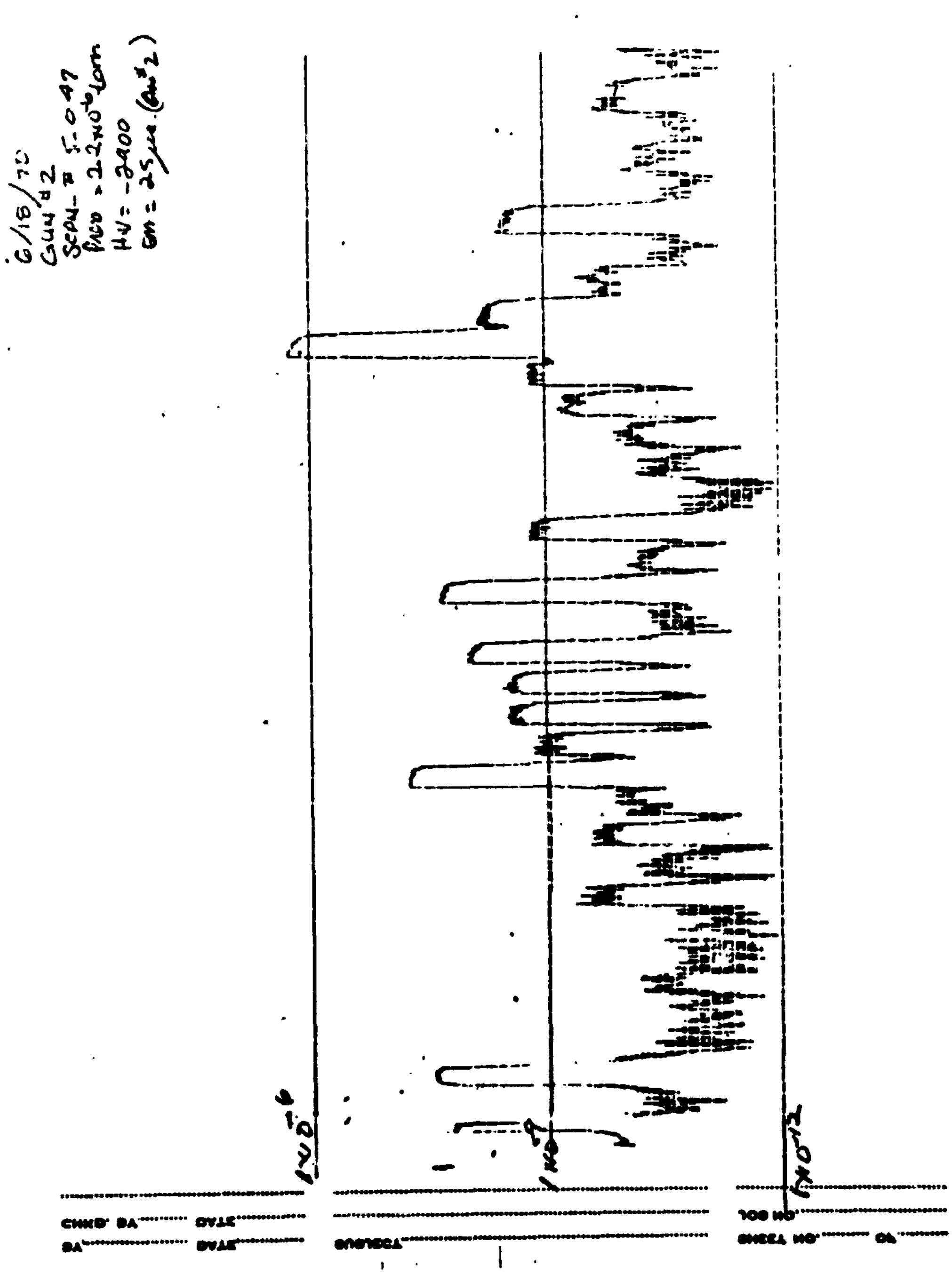

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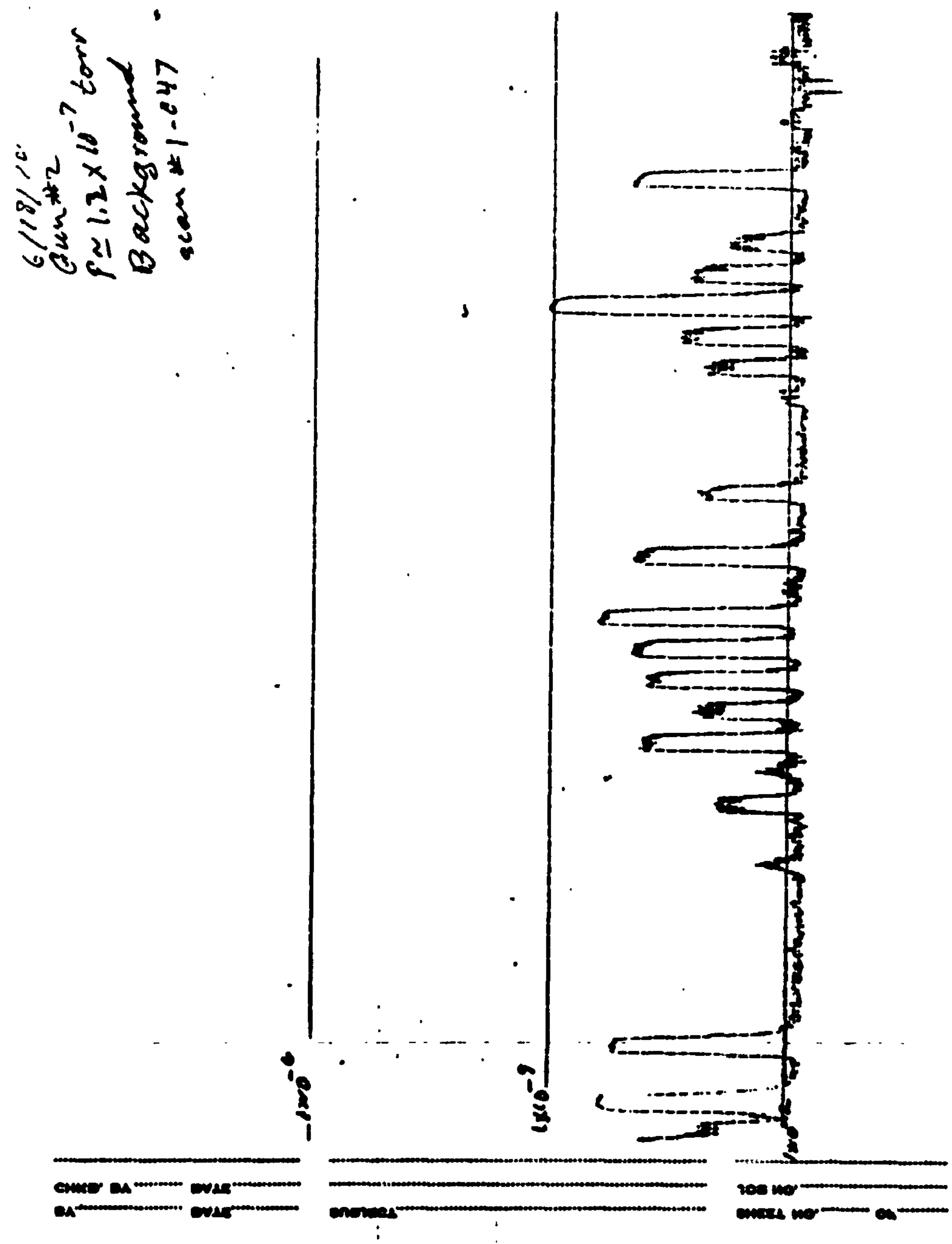

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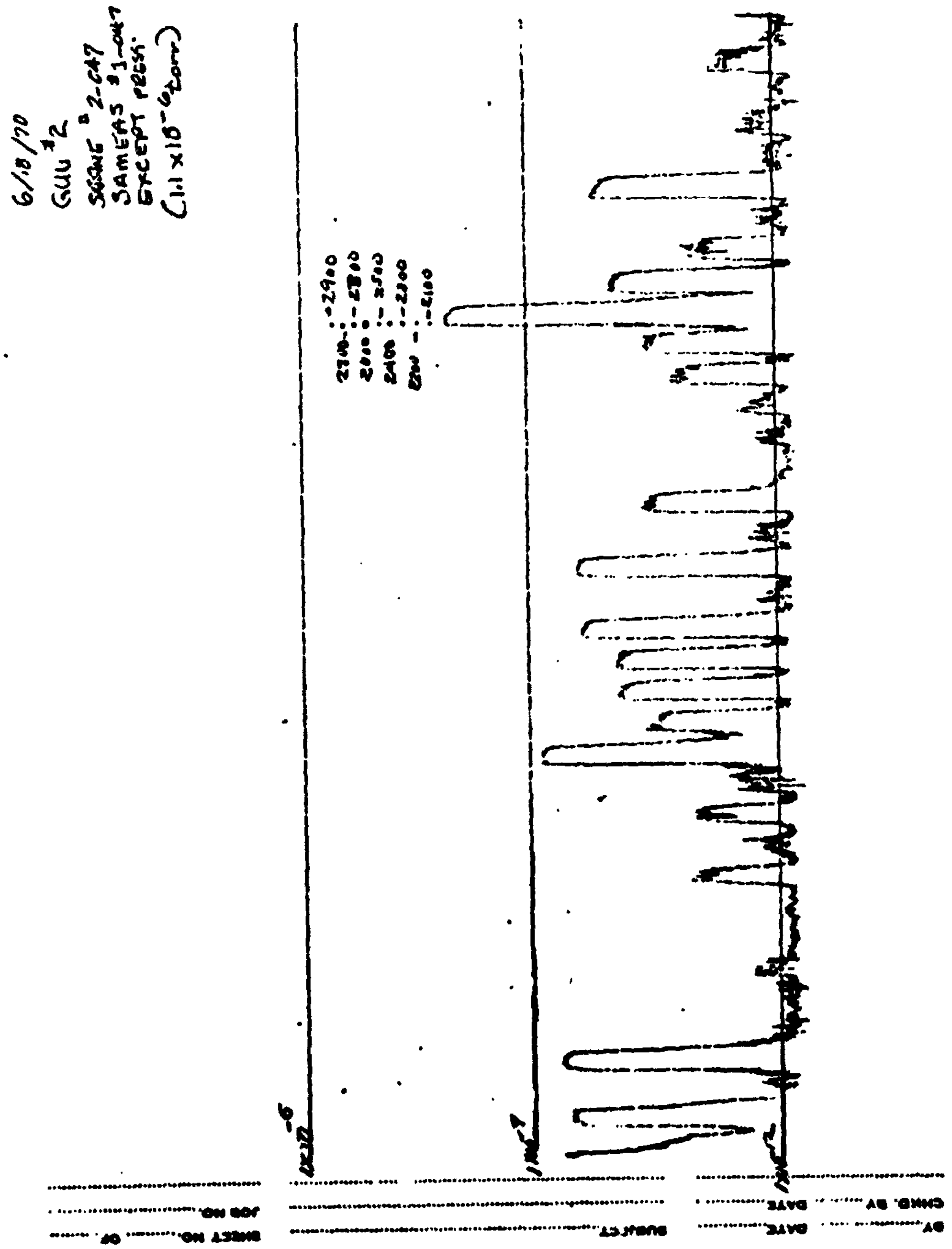

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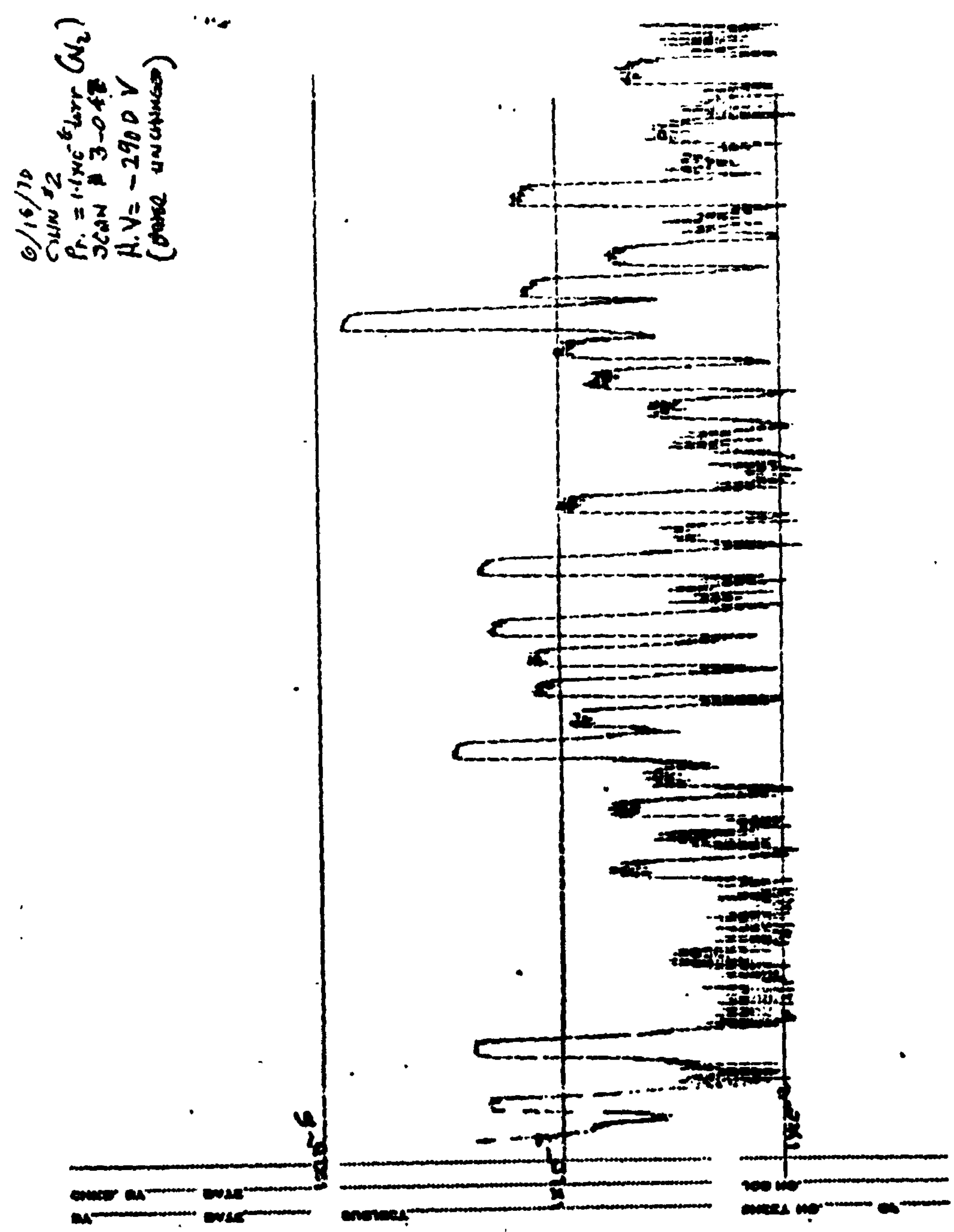

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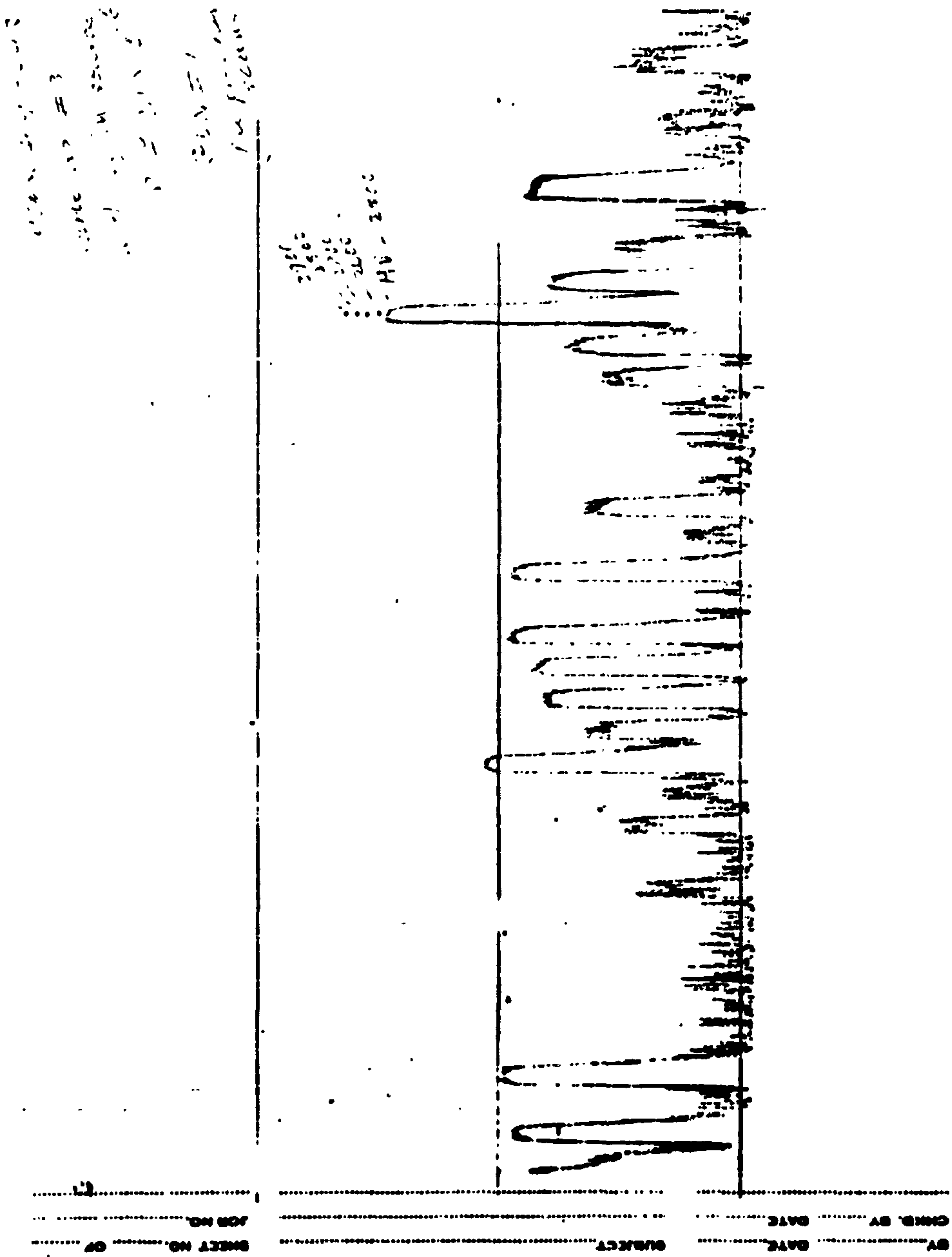

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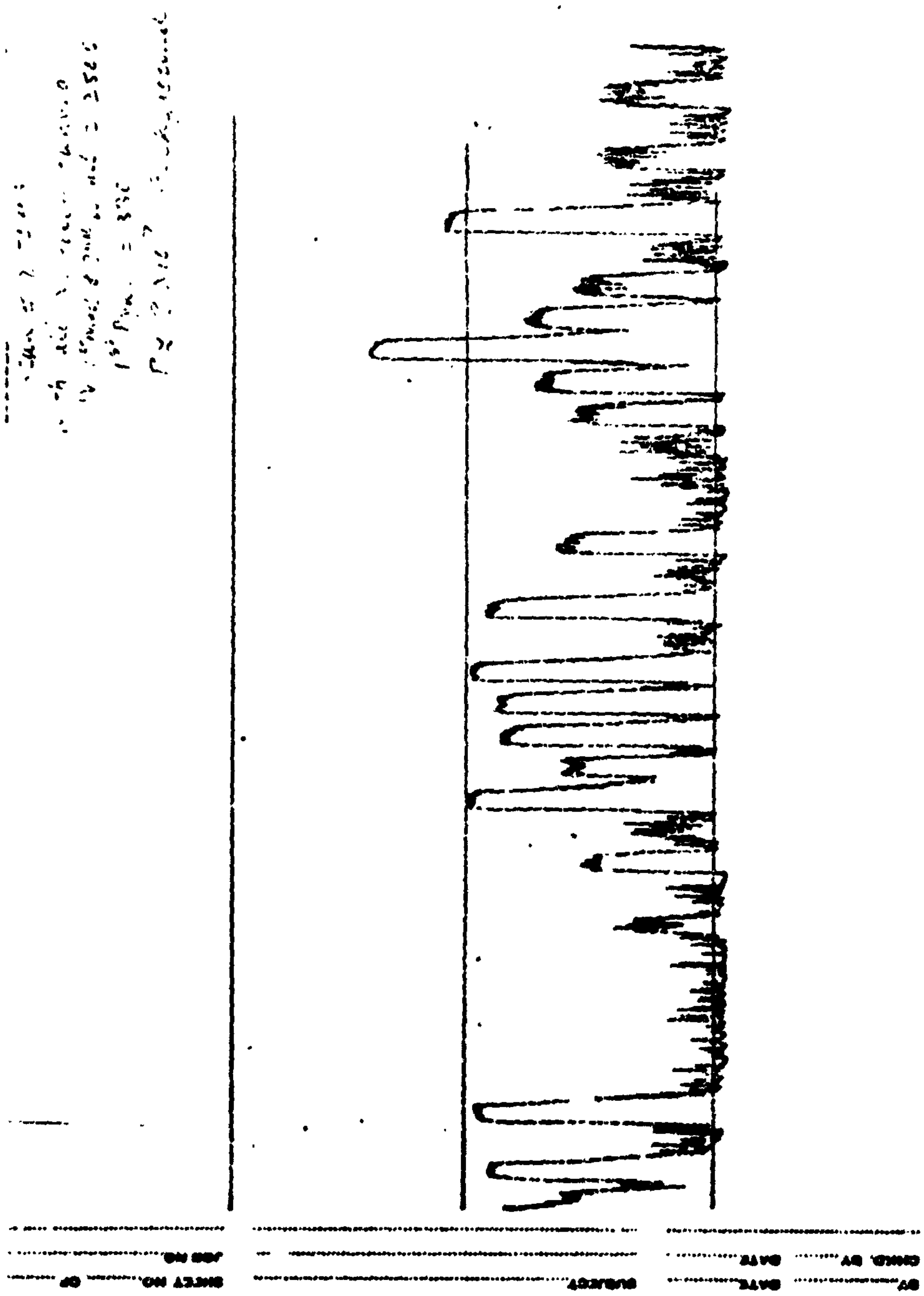

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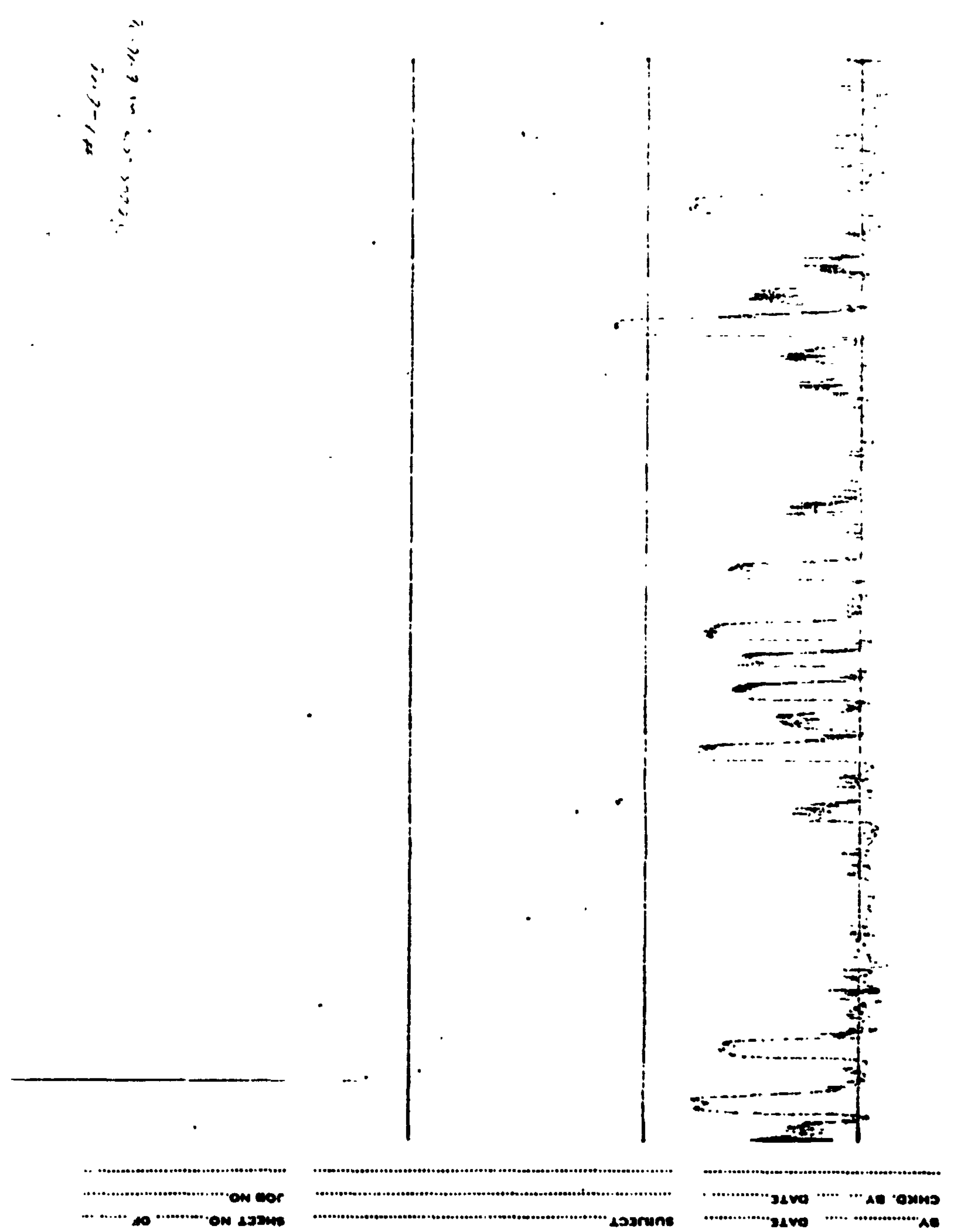

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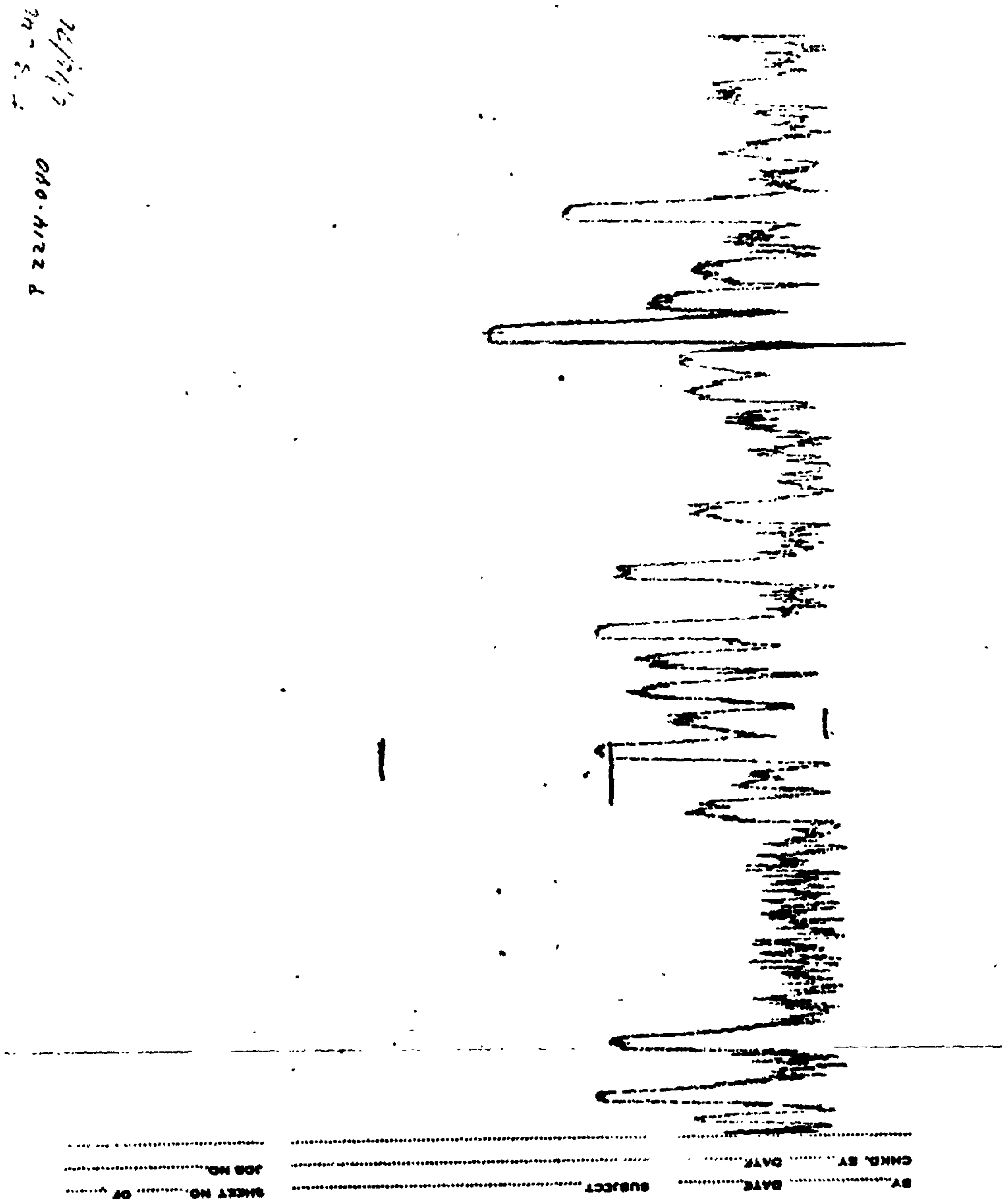
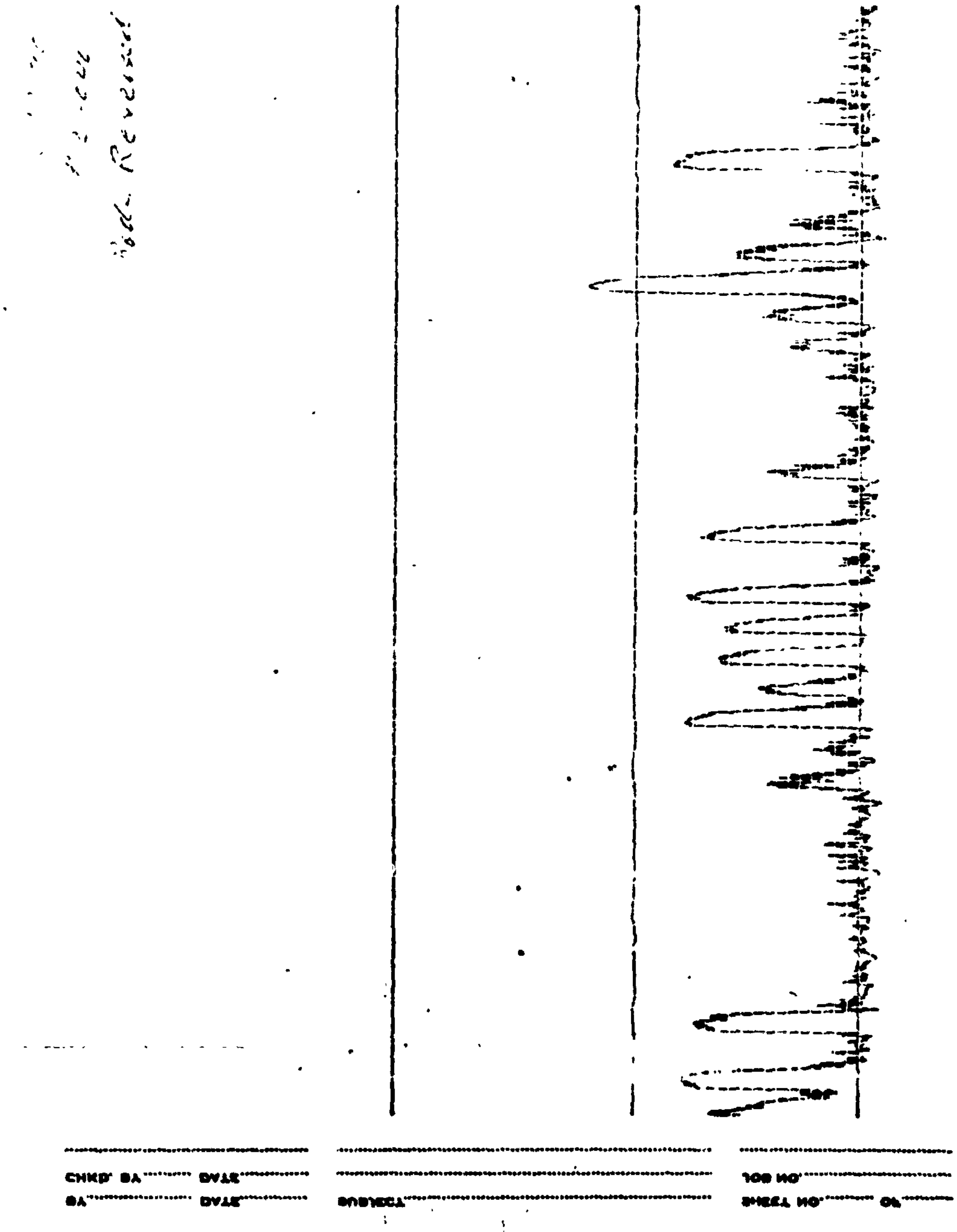
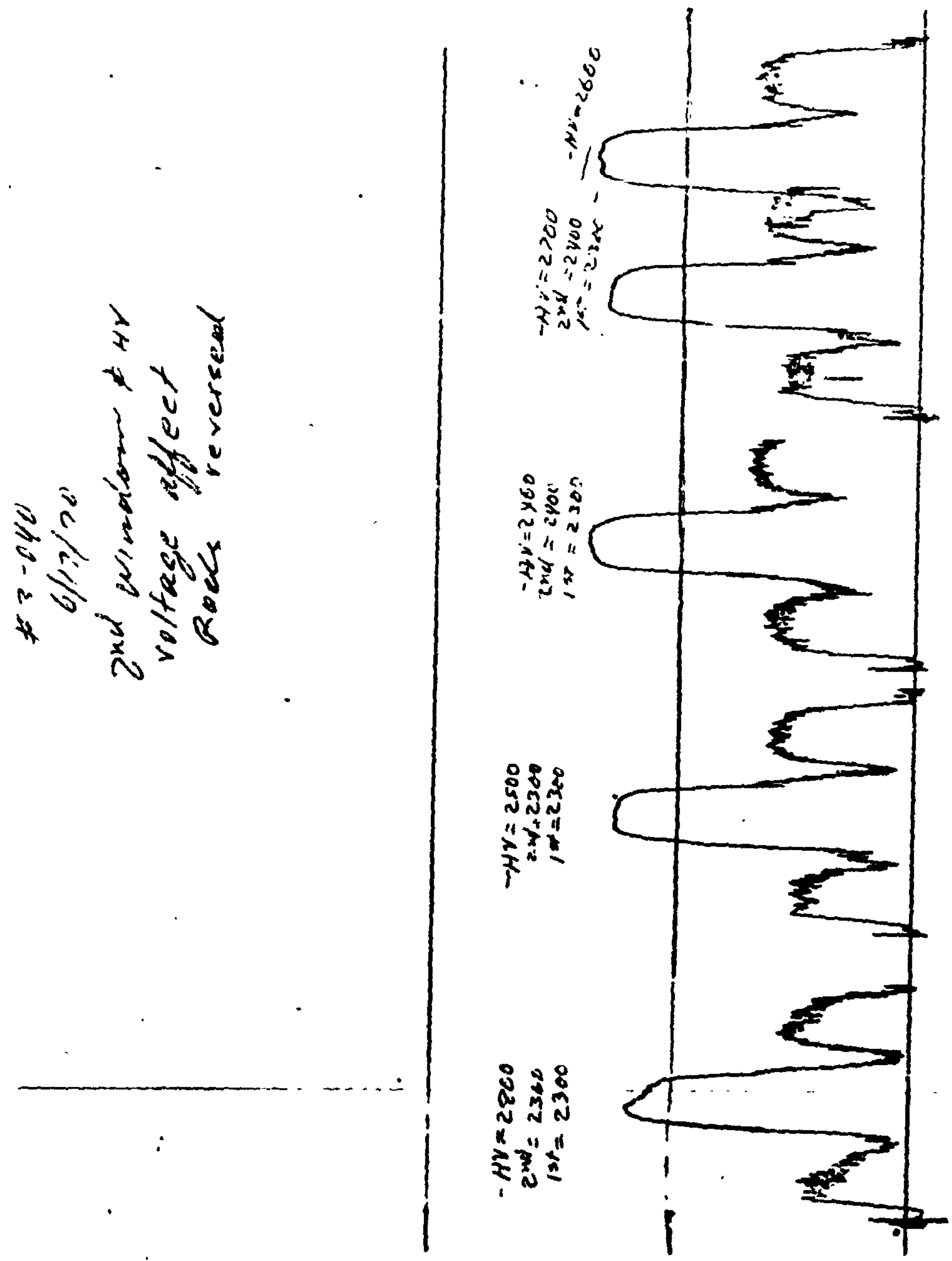
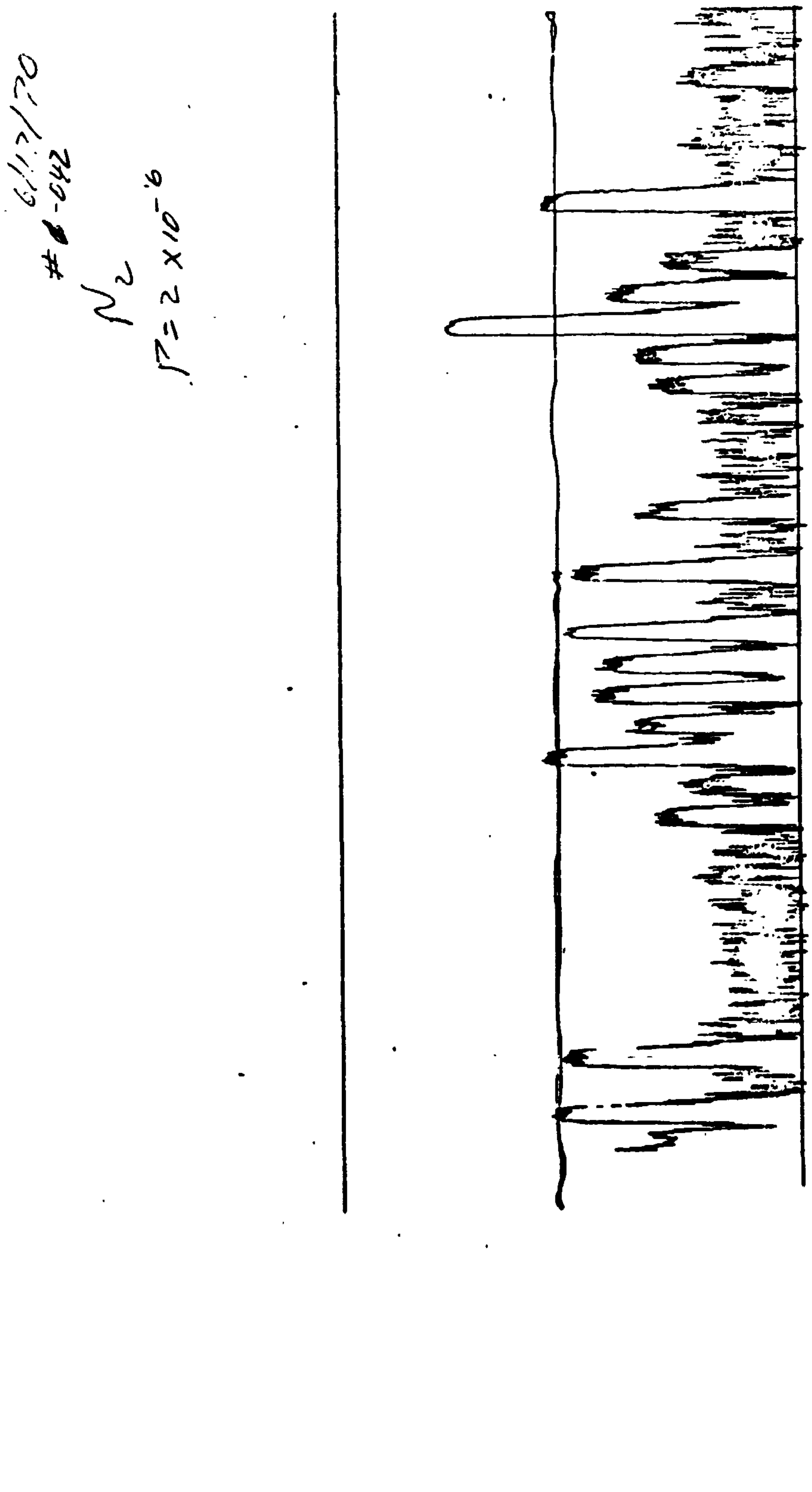


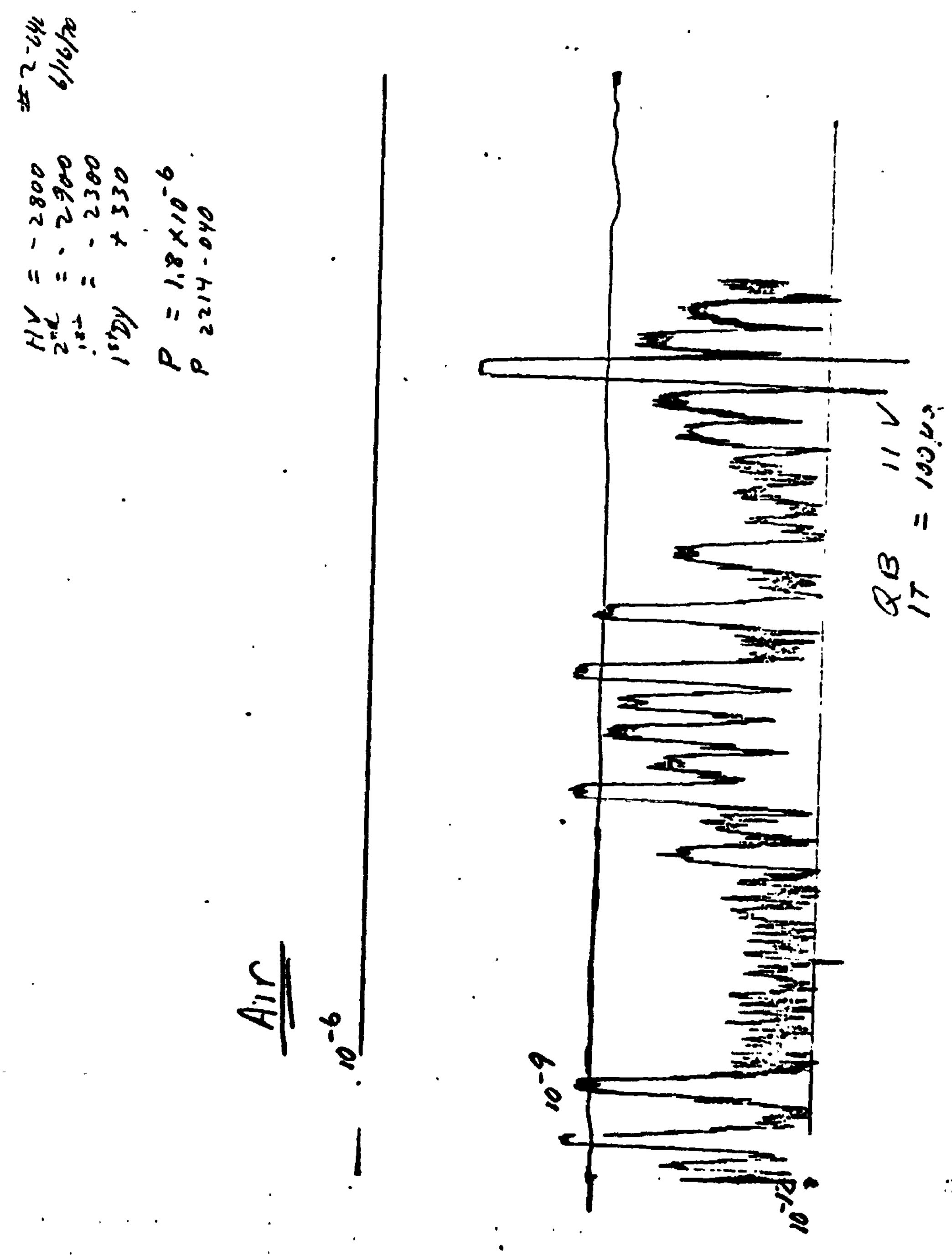
APPENDIX C



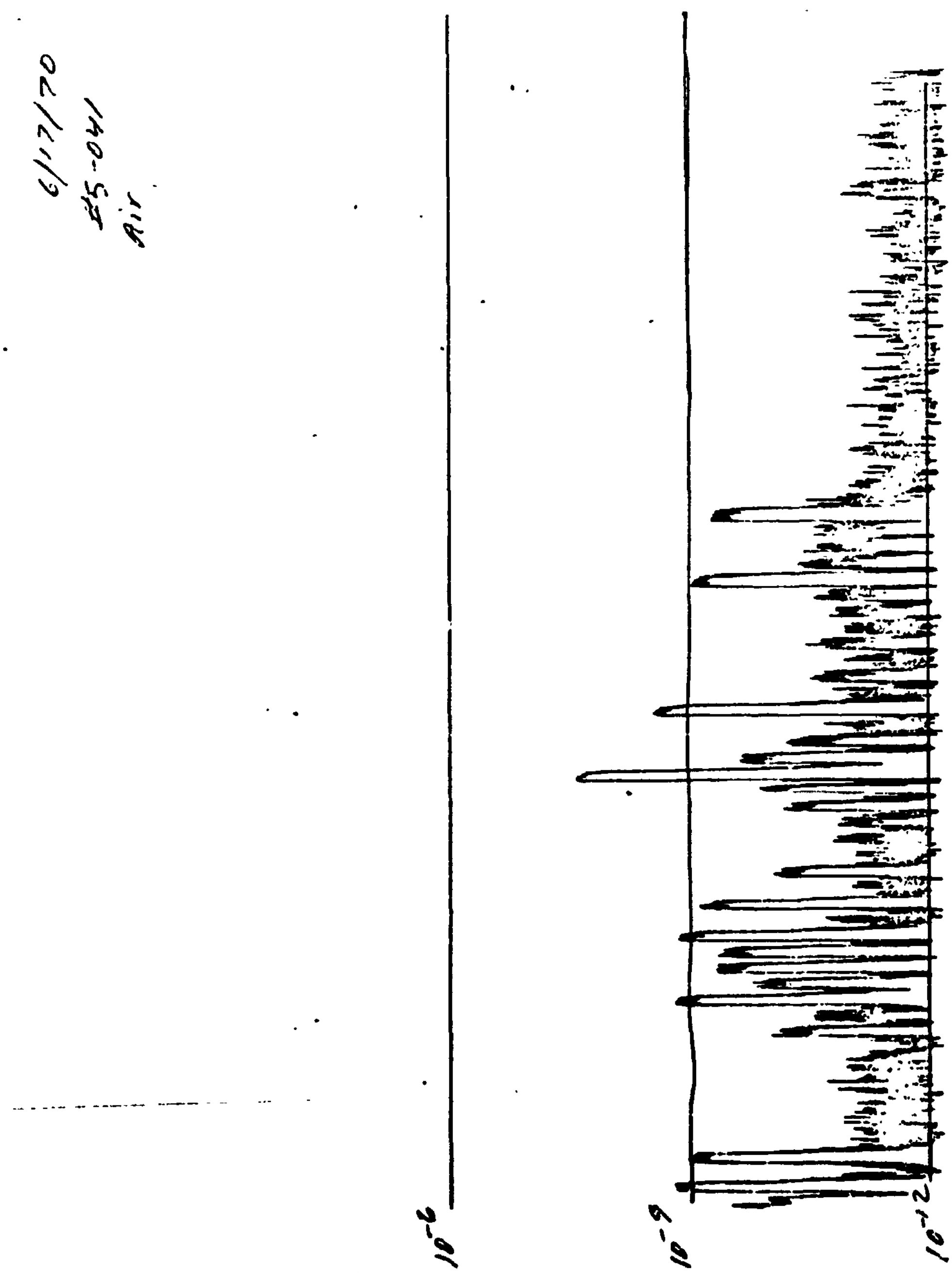

#3-040
6/17/70
2nd window & HV
voltage affect
Rods reversed
-HV=2800
2nd= 2360
1st= 2300
-HV= 2500
2nd=2300
1st=2300
-HV=2460
2nd = 2400
1st = 2300
-HV=2700
2nd =2400
1st =2300
-HV=2600

APPENDIX C

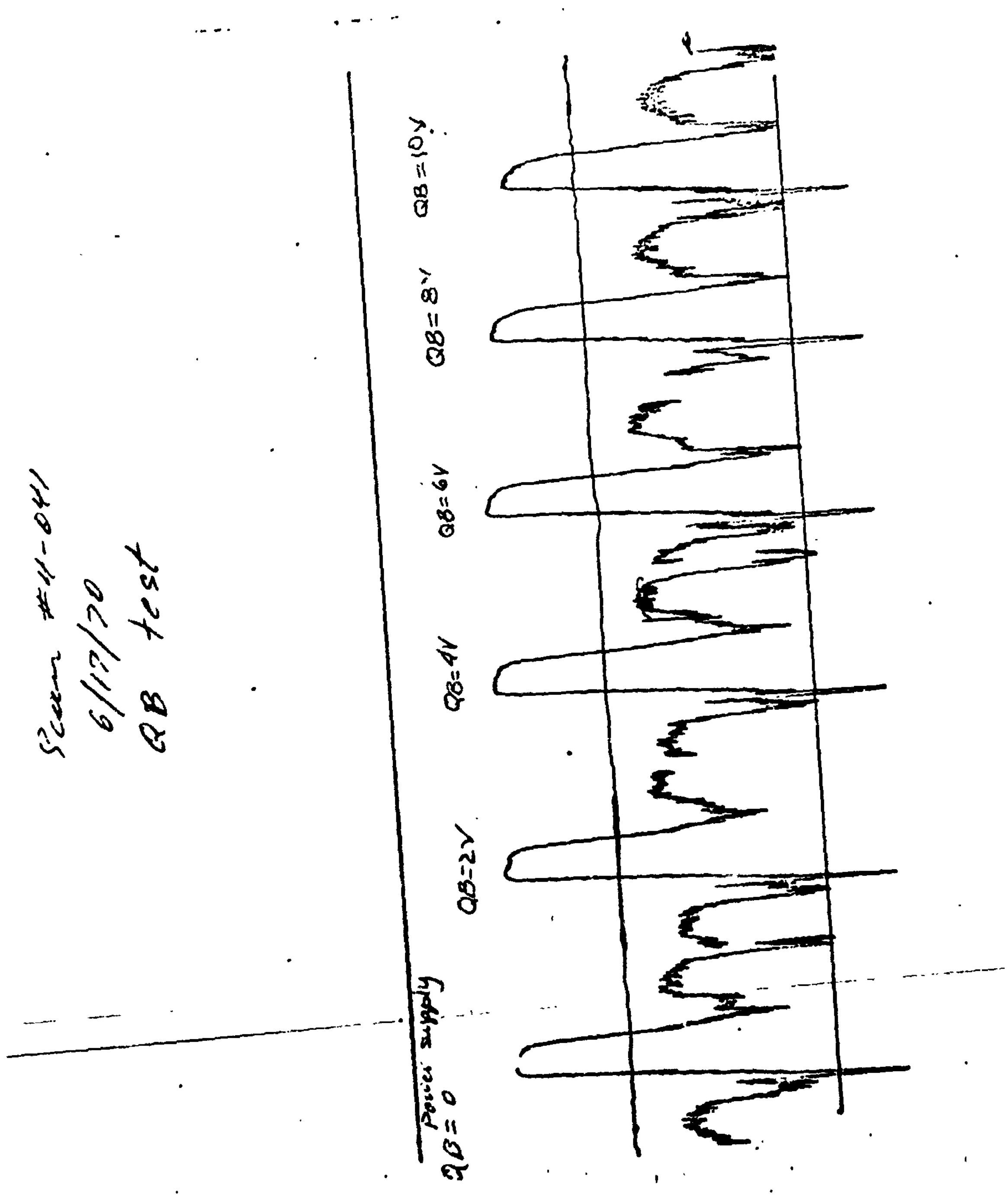



HV = -2800
P = 1.8 x 10^-6
Air
10^-6
10^-9
RB
11 V

APPENDIX C

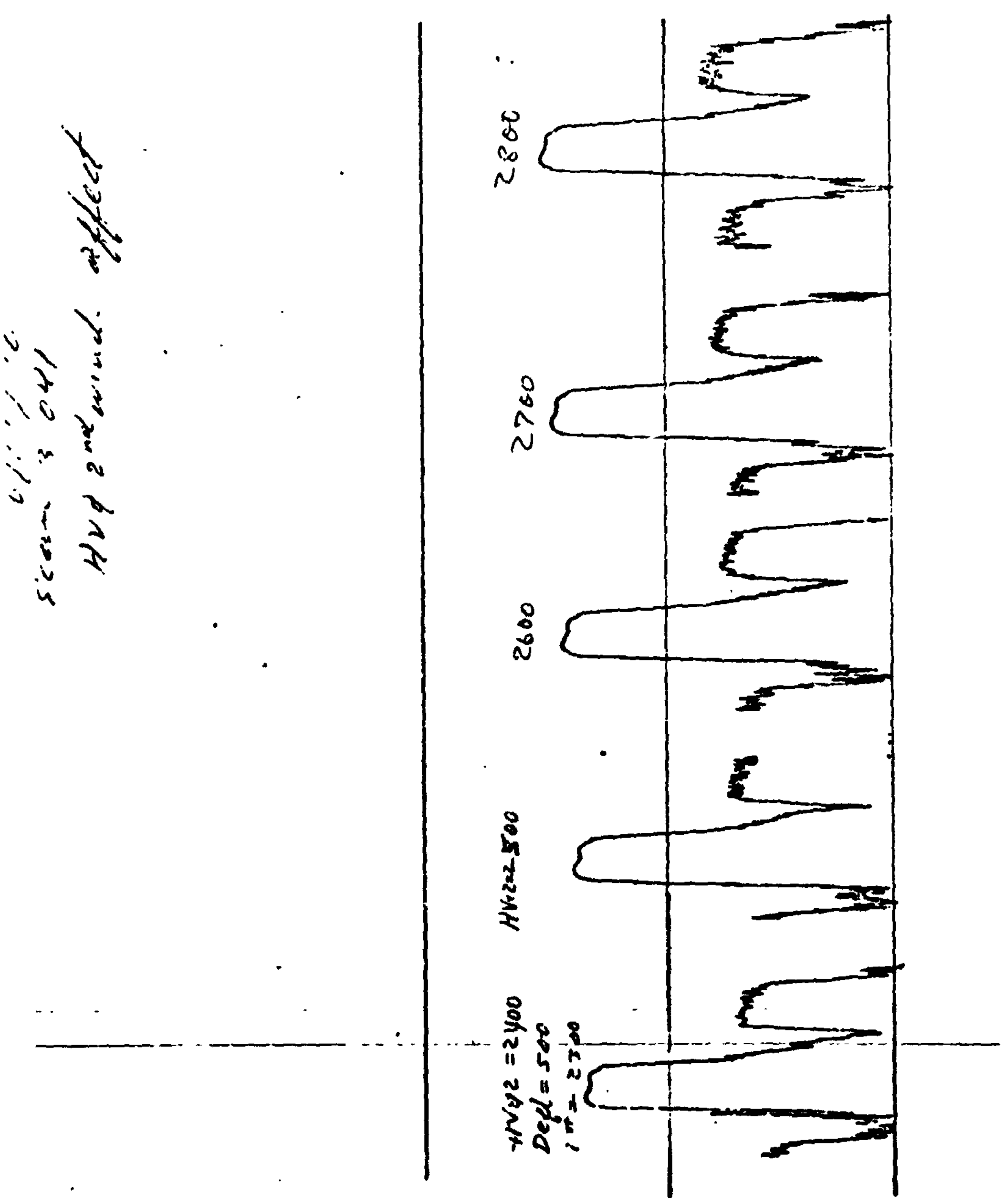


APPENDIX C

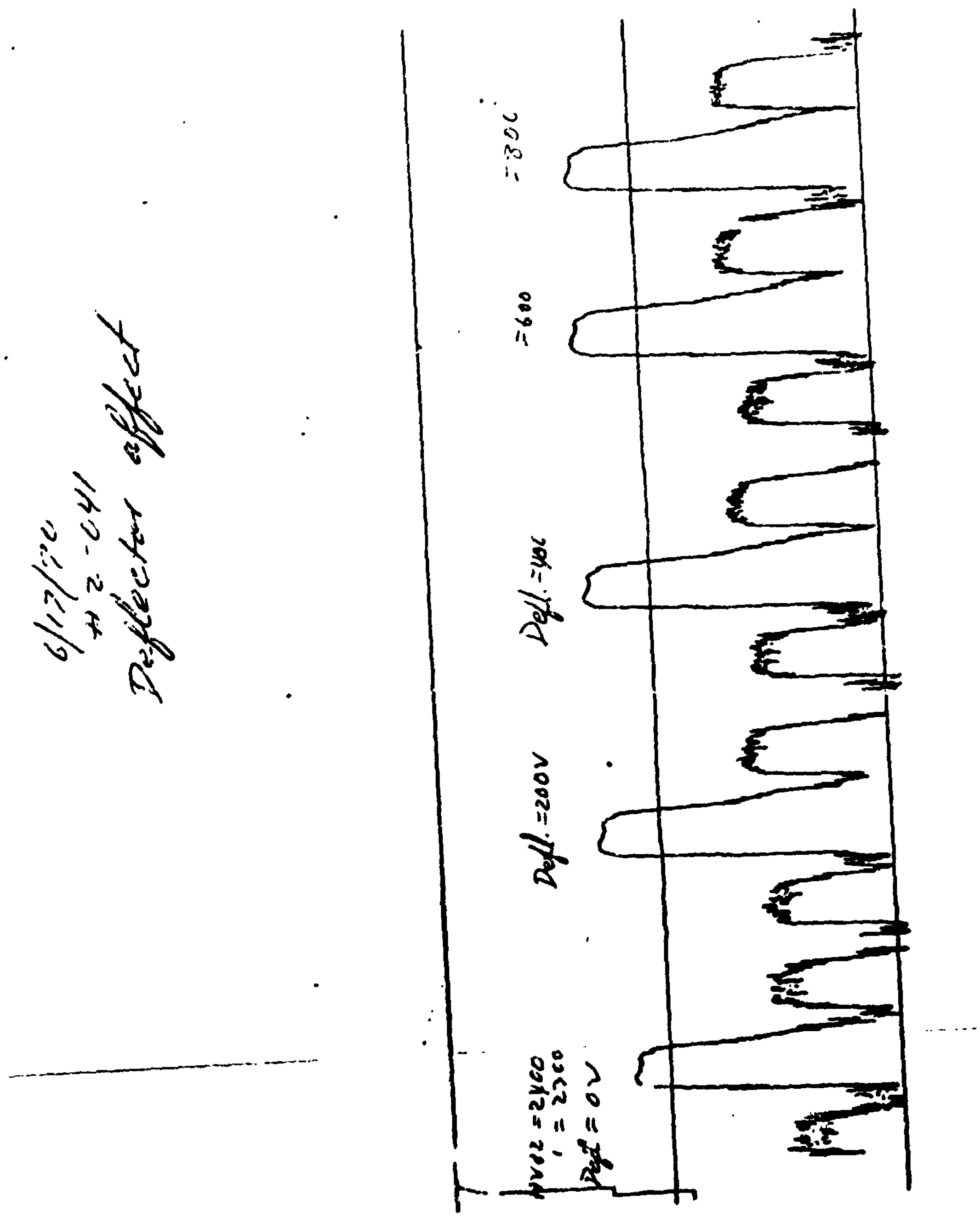


Scan #11-041
6/17/70
QB test
QB=0
Power supply
QB=2V
QB=4V
QB=6V
QB=8V
QB=10V

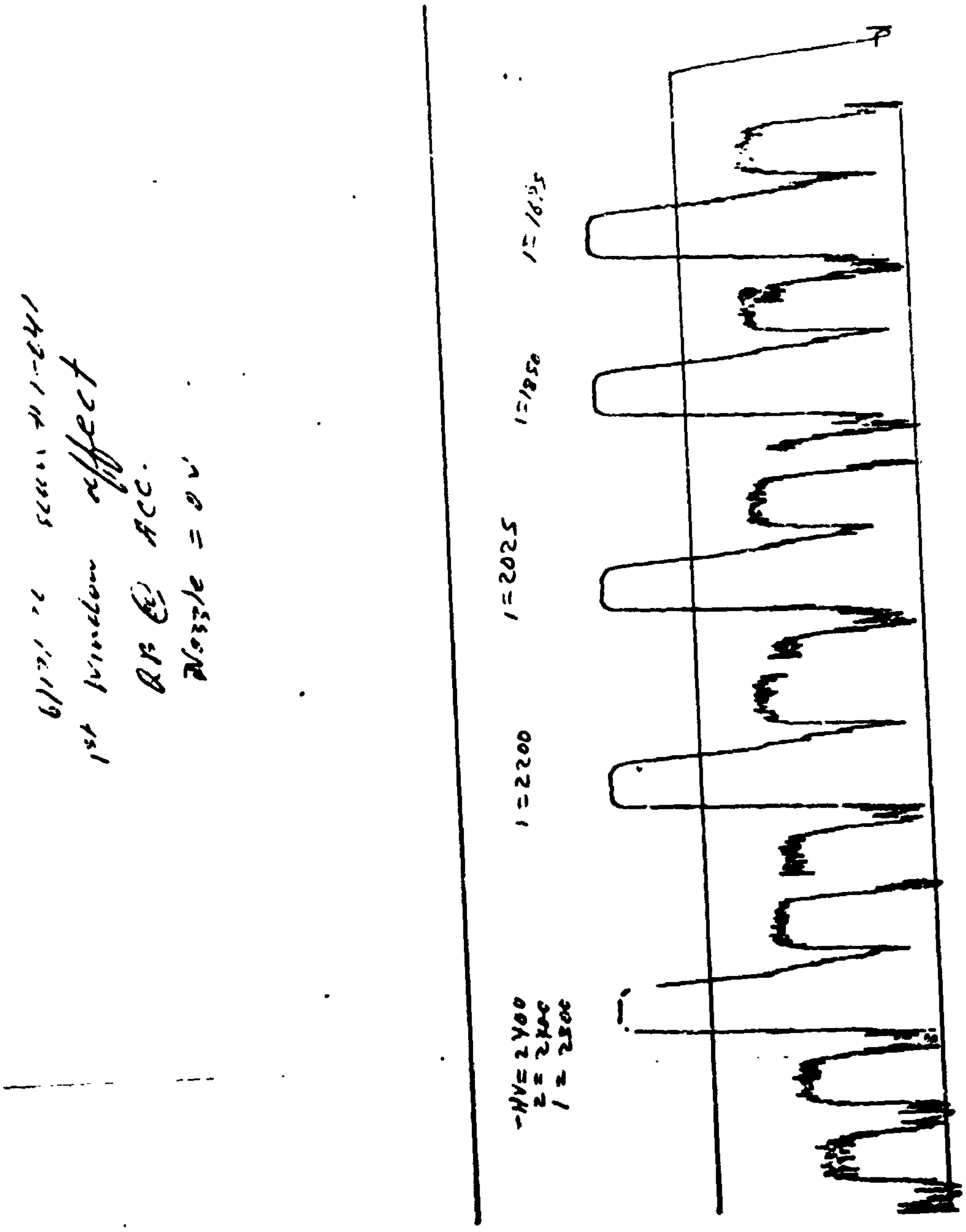
APPENDIX C



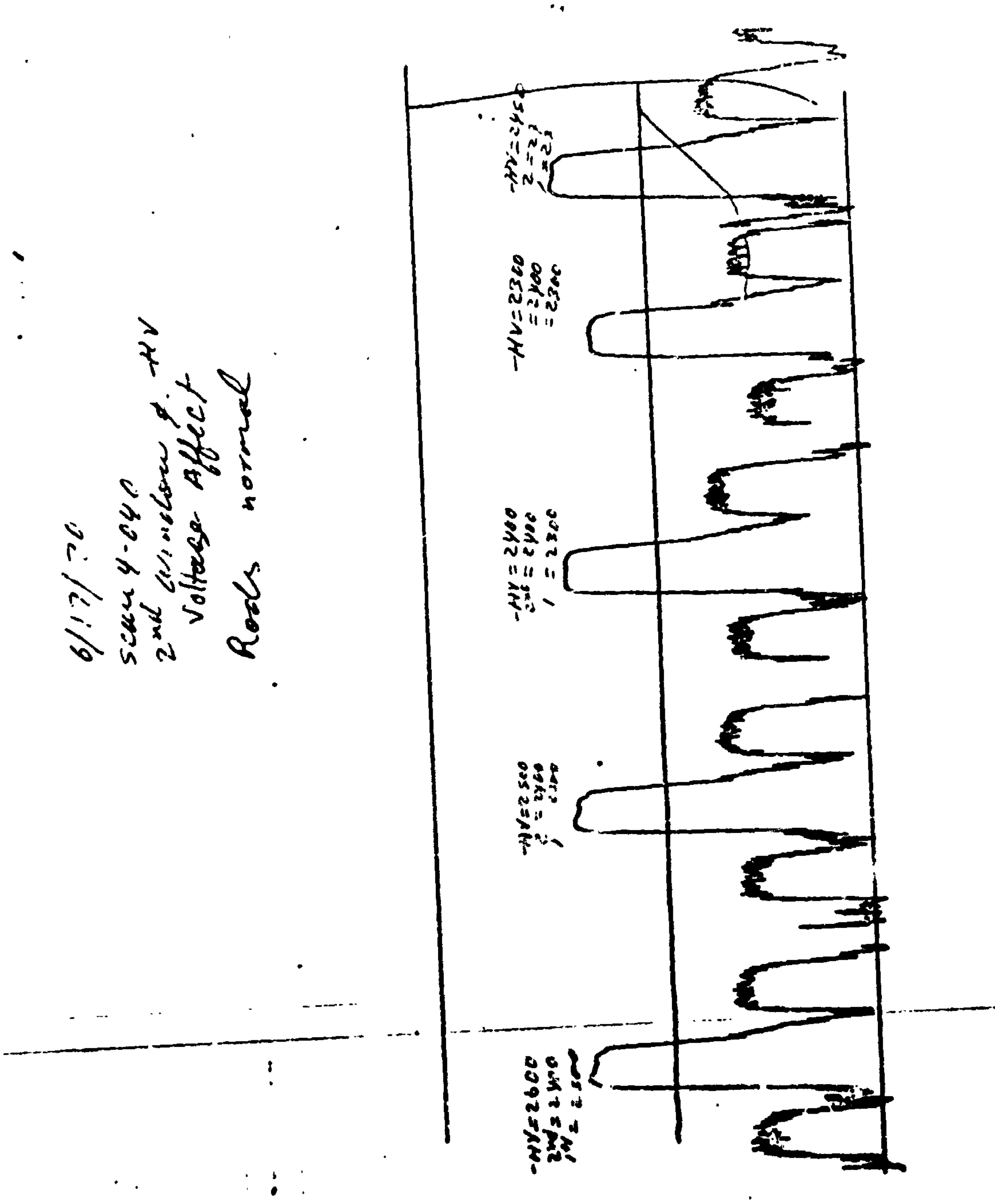
APPENDIX C



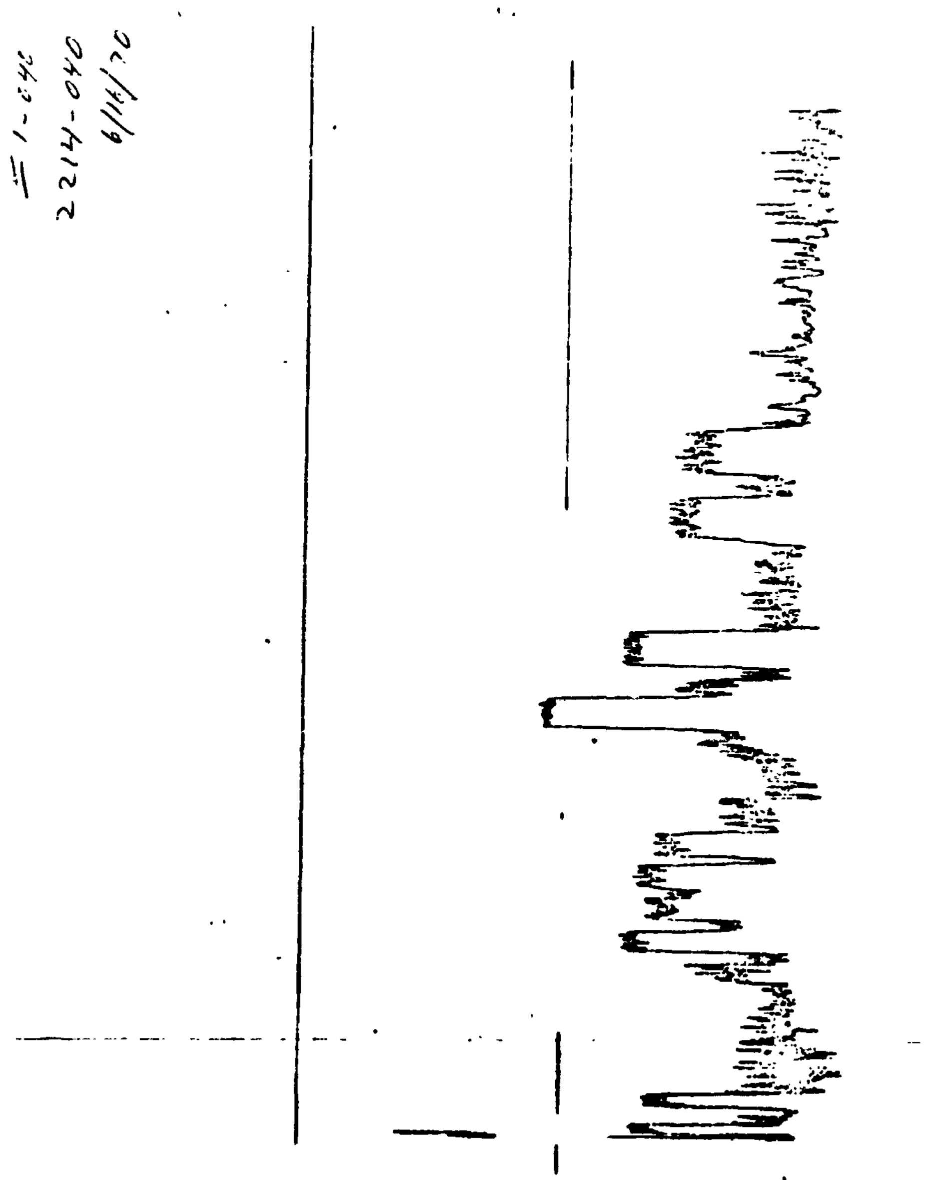
APPENDIX C



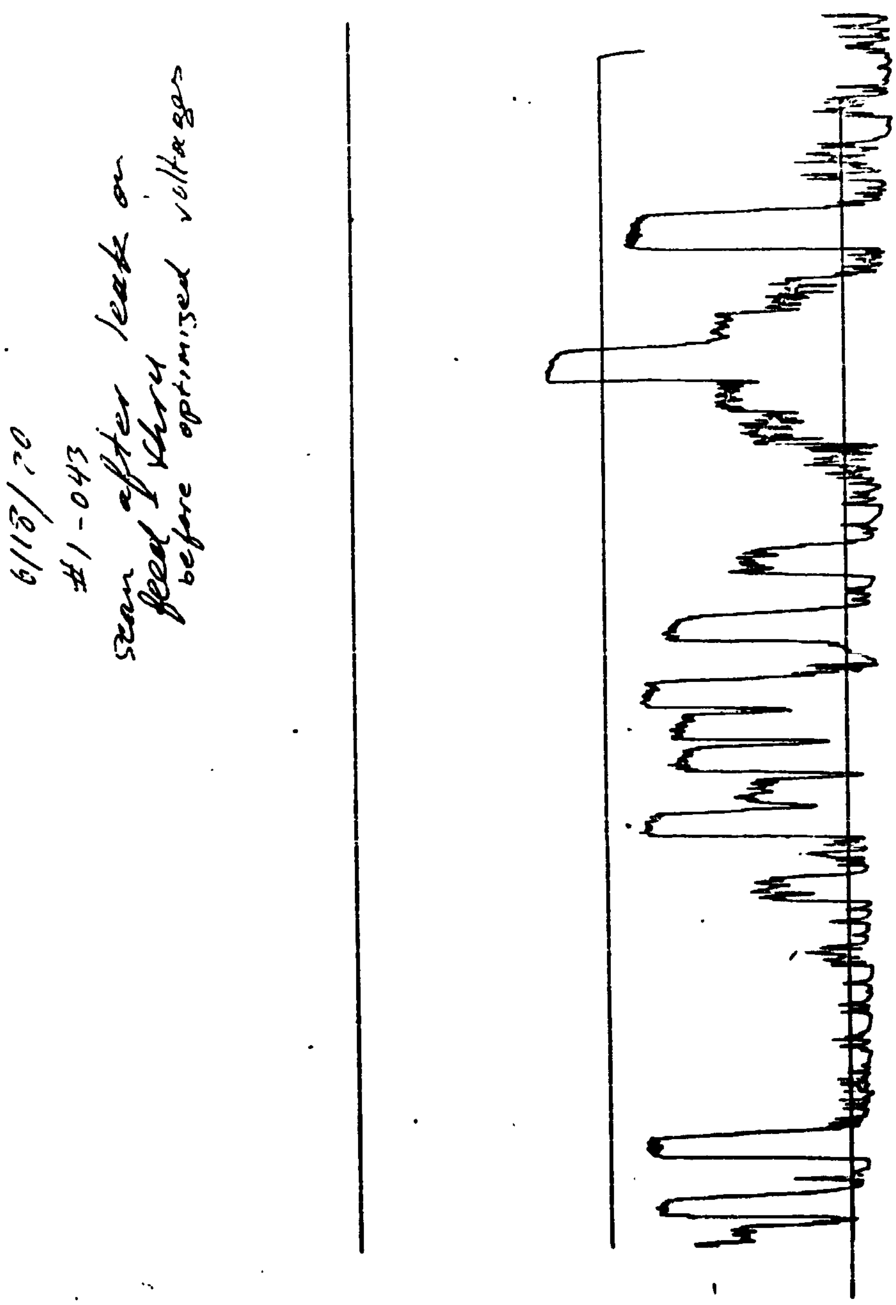
APPENDIX C


6/17/70
Scan 4-04C
2nd window & HV
Voltage Affect
Reads normal
-HV=2450
-HV=2300
-HV=2400
-HV=2500
-HV=2600

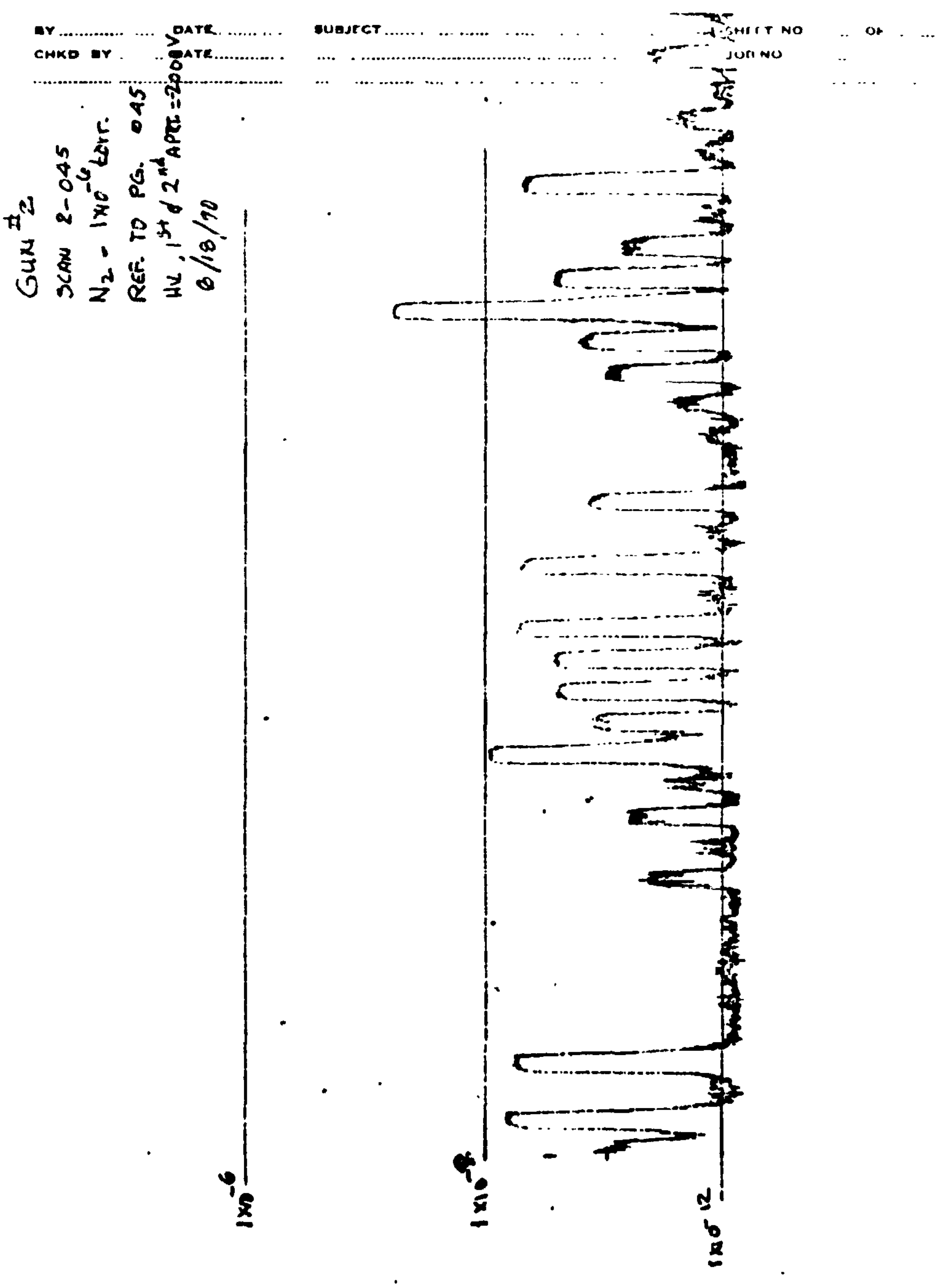
APPENDIX C



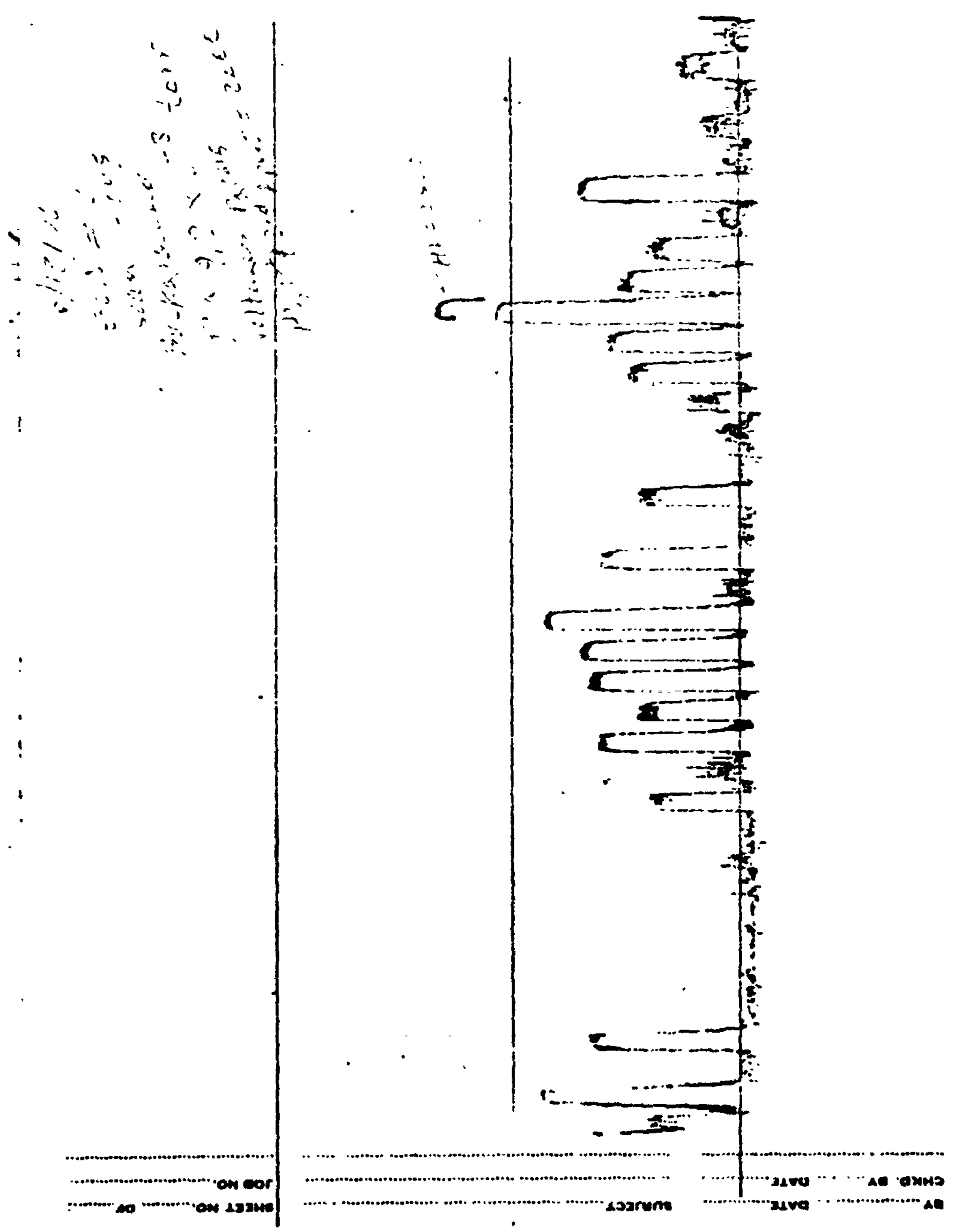
APPENDIX C


6/18/70
#1-043
Scan after leak on
feed I thru
before optimized voltages

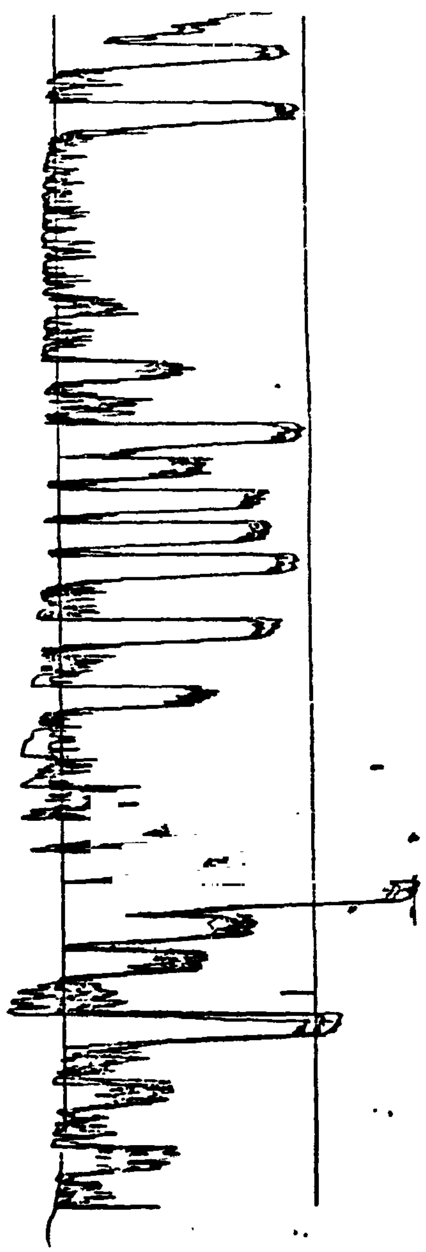
APPENDIX C


BY
DATE
SUBJECT
SHEET NO
OF
CHKD BY
DATE
JOB NO
GUN #2
SCAN 2-045
N2 - 1x10^-6 torr
REF. TO PG. 045
HV, 1st & 2nd APRT = 200V
8/10/90
1x10^-6
1x10^-9
1x10^-12

APPENDIX C



APPENDIX C



$$\frac{6 \times 10^{-8}}{1 \times 10^{5}}$$

$$\frac{6 \times 10^{-13}}{1 \times 10^{-6}}$$

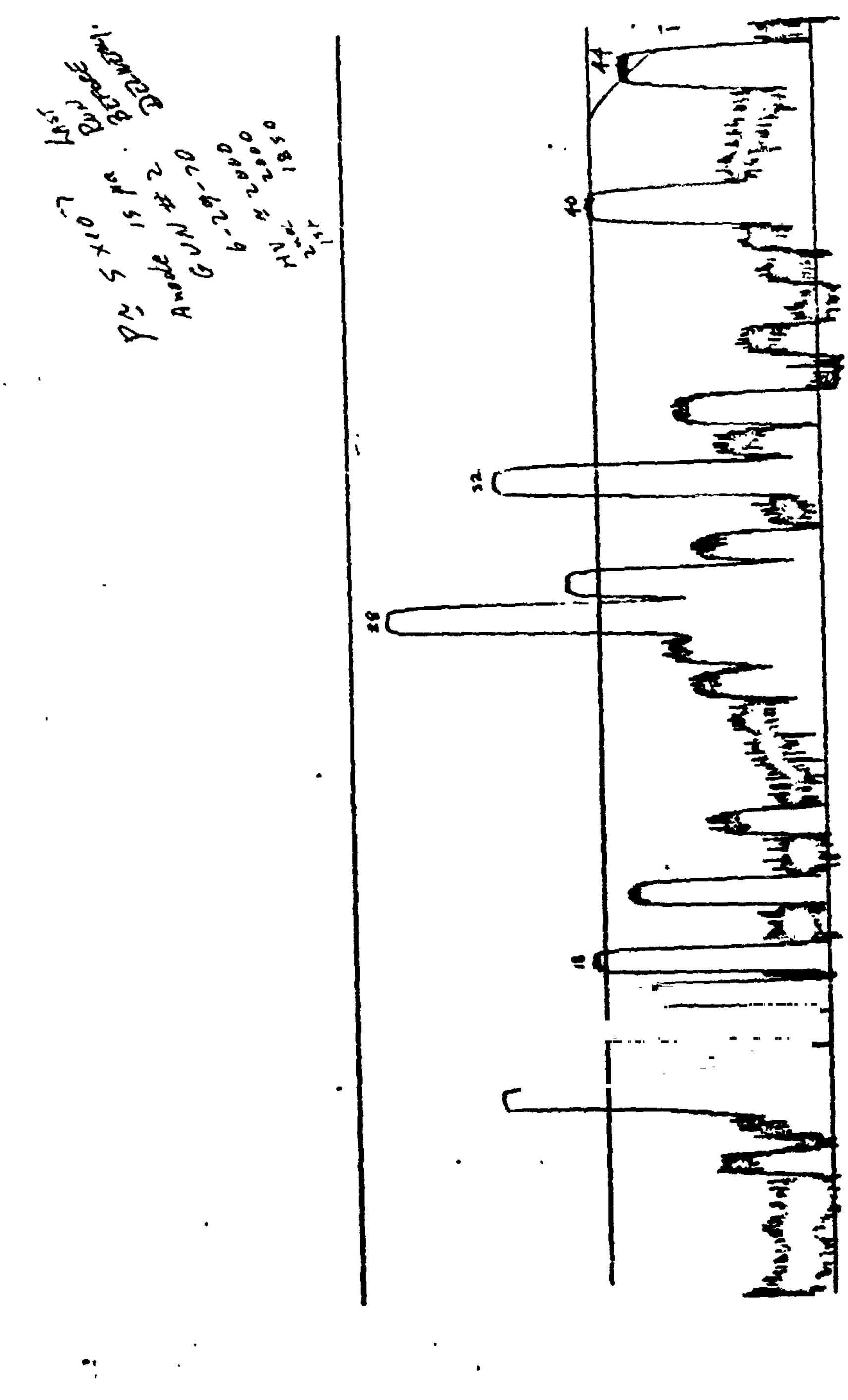
$$6 \times 10^{-7}$$

$$\frac{1.5 \times 10^{-7}}{\times 10^{6}}$$

$$\frac{1.5 \times 10^{-13}}{1 \times 10^{-6}}$$

$$1.5 \times 10^{-7}$$

APPENDIX C



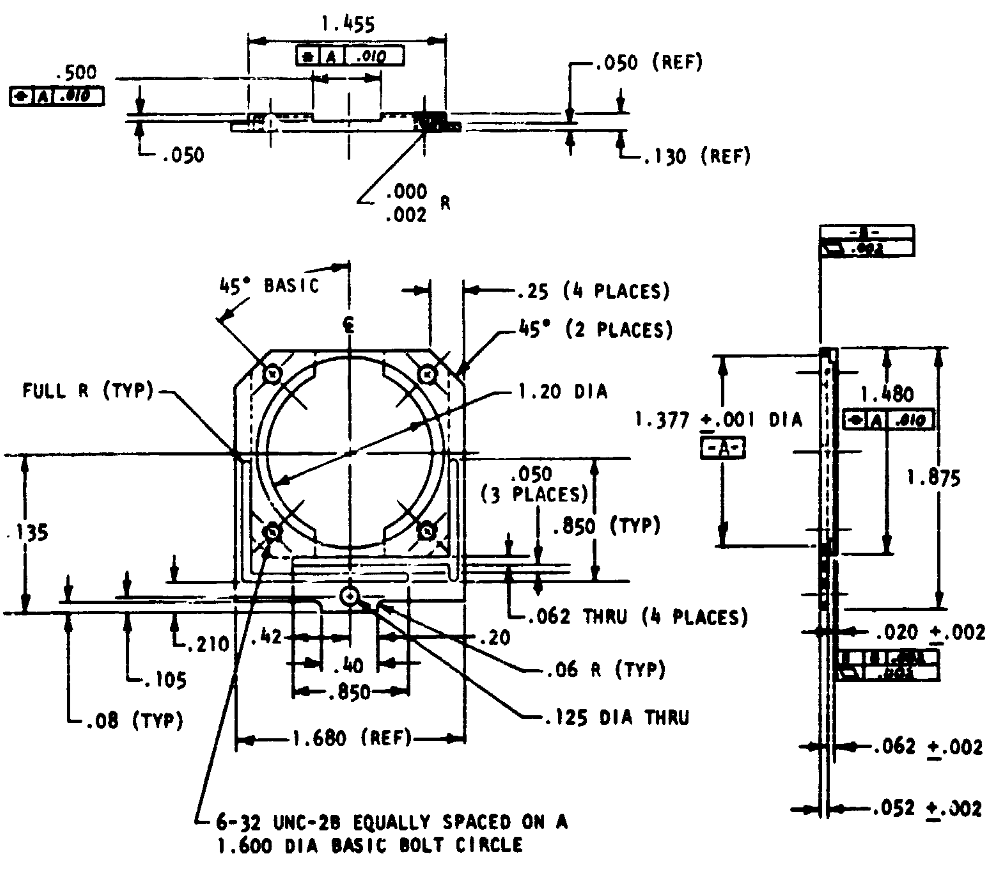


FIGURE 1. Flexure Plate

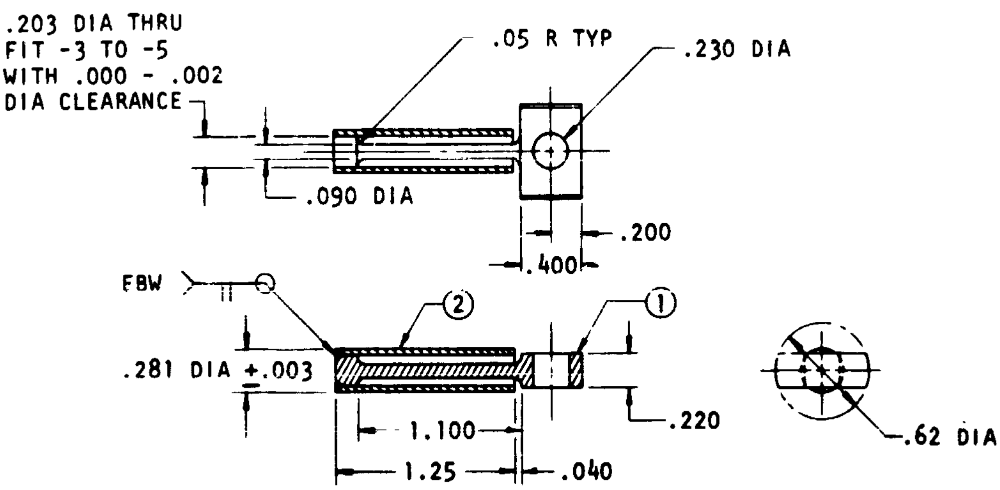


FIGURE 2. Flexure Rod Assembly

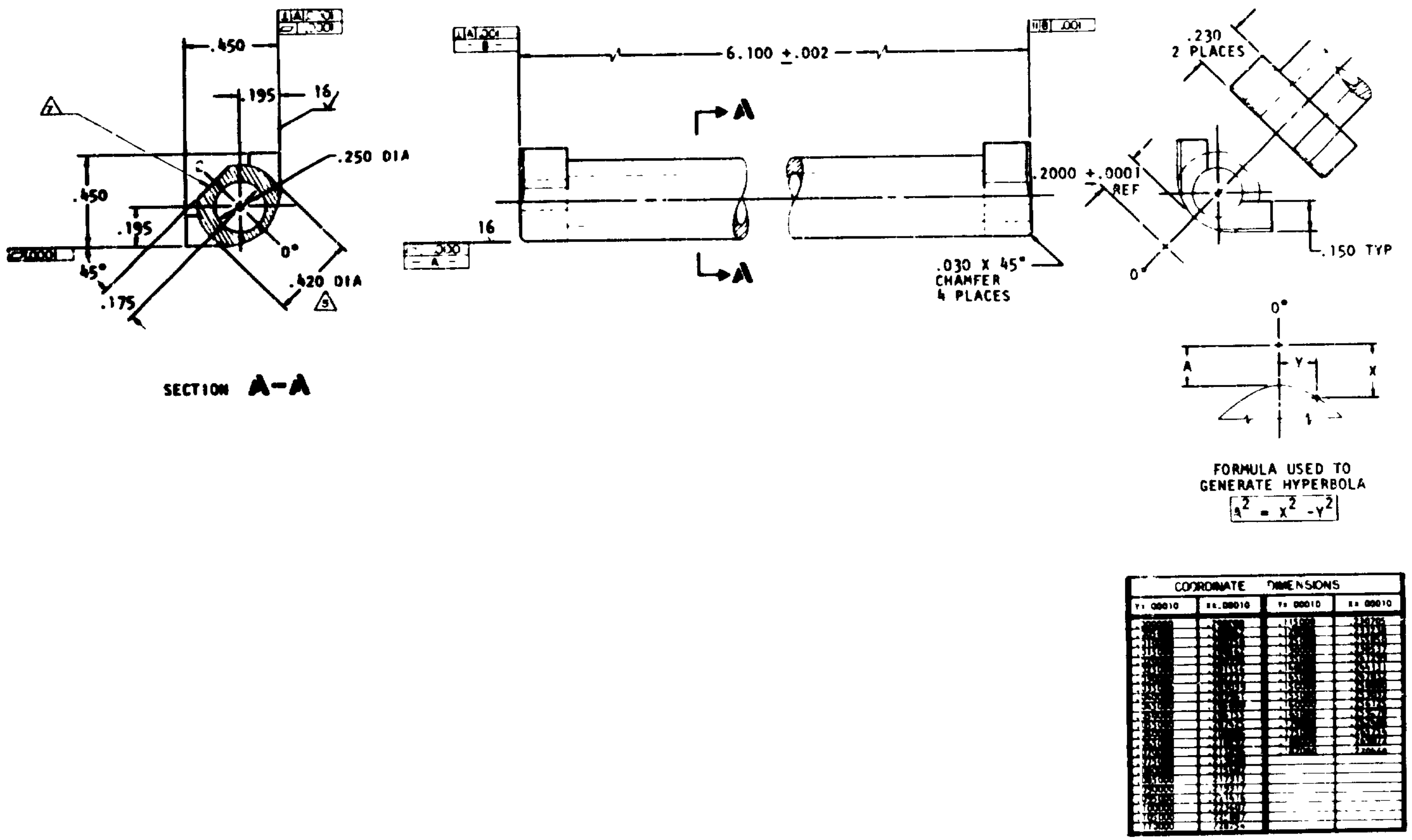
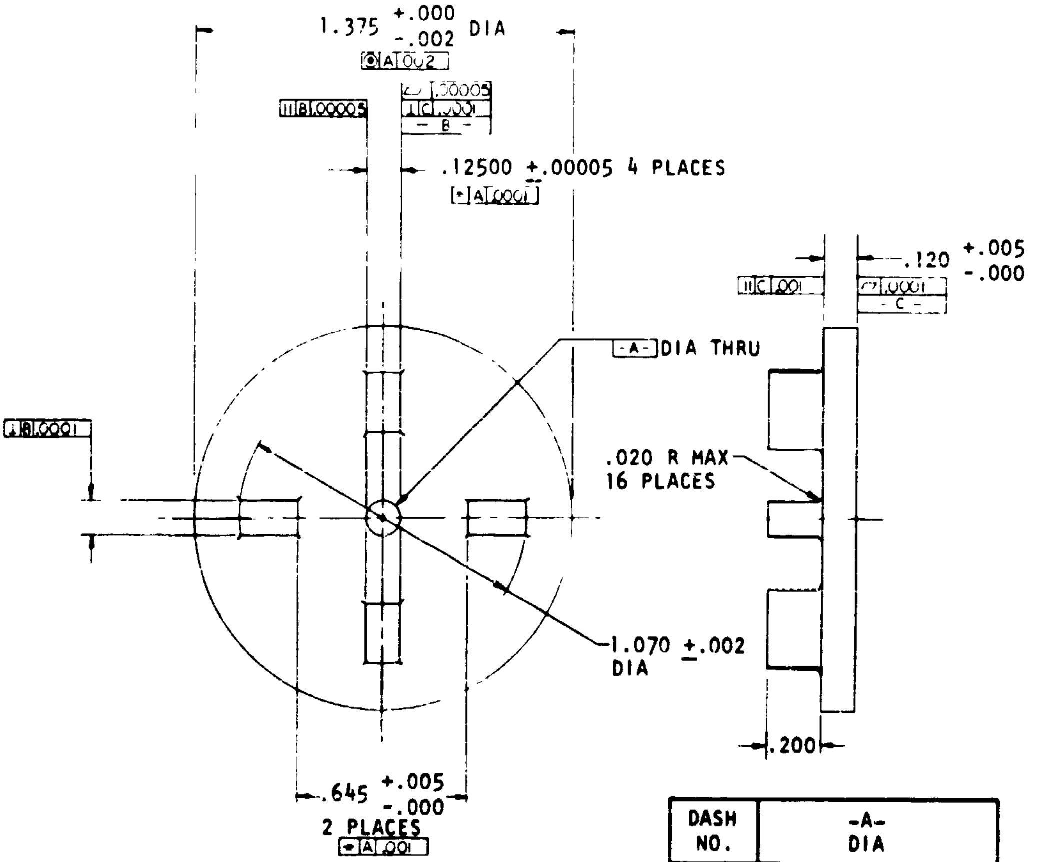


FIGURE 3. Hyperbolic Quadrupole Rod



DASH NO.	-A- DIA
-1	.1250 +.0002 -.0000
-3	.647 ±.002

NOTES: UNLESS OTHERWISE SPECIFIED

1. MATL: HIGH STRENGTH ALUMINA CERAMIC, 96% AL_2O_3 OR GREATER

2. RESISTIVITY OF MATL TO BE MINIMUM OF 10^{14} OHM-CM AT 25°C

3. PART TO BE SERIALIZED, BAG AND TAG DO NOT MARK PART

FIGURE 4. Ceramic Rod Spacing Plate

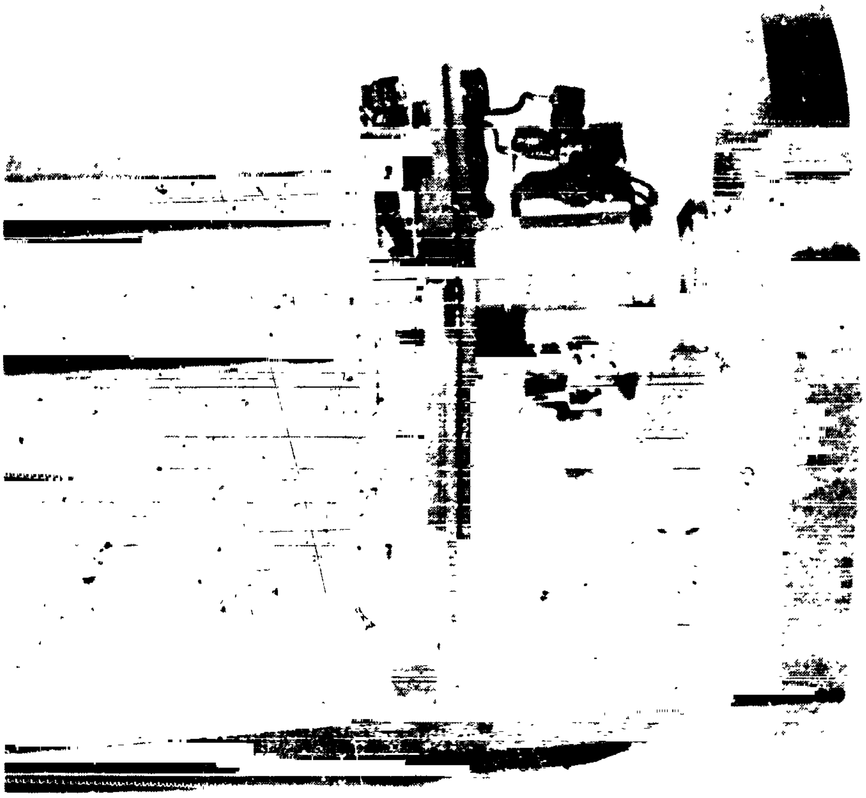


FIGURE 5. Dual Filament Ion Source

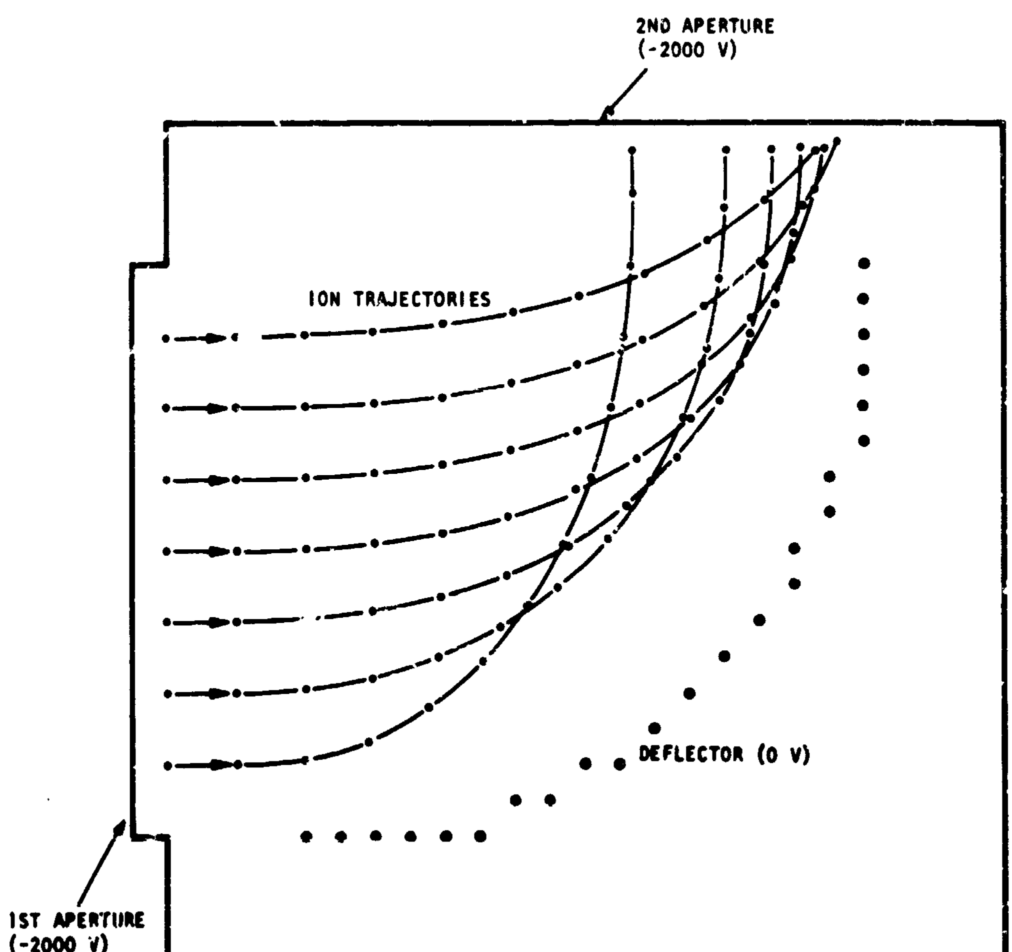


FIGURE 6. Trajectory Plots

FIGURE 7. Quadrupole Mass Spectrometer Assembly

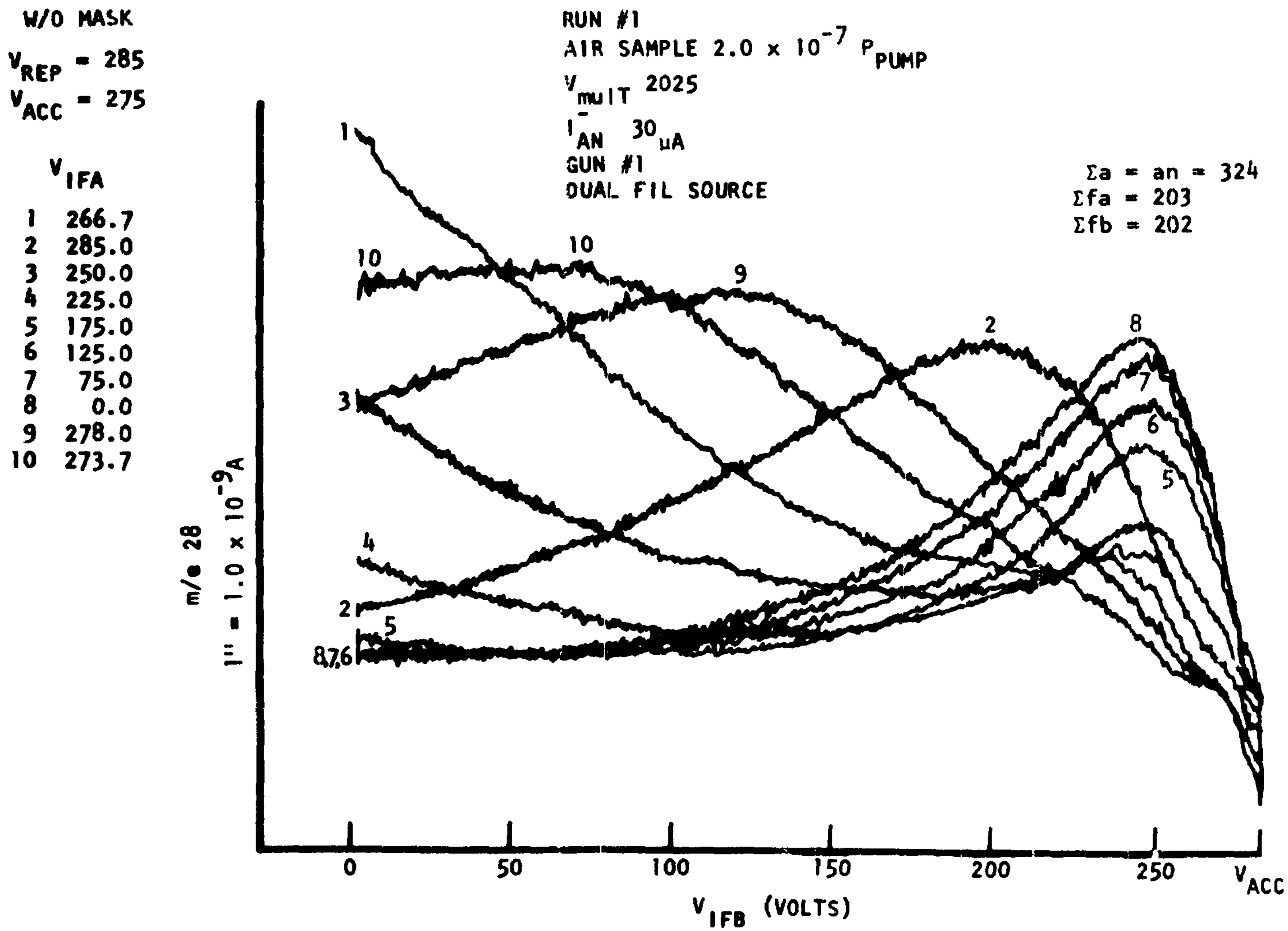


FIGURE 8. Ion Focusing Curves (Lens A)

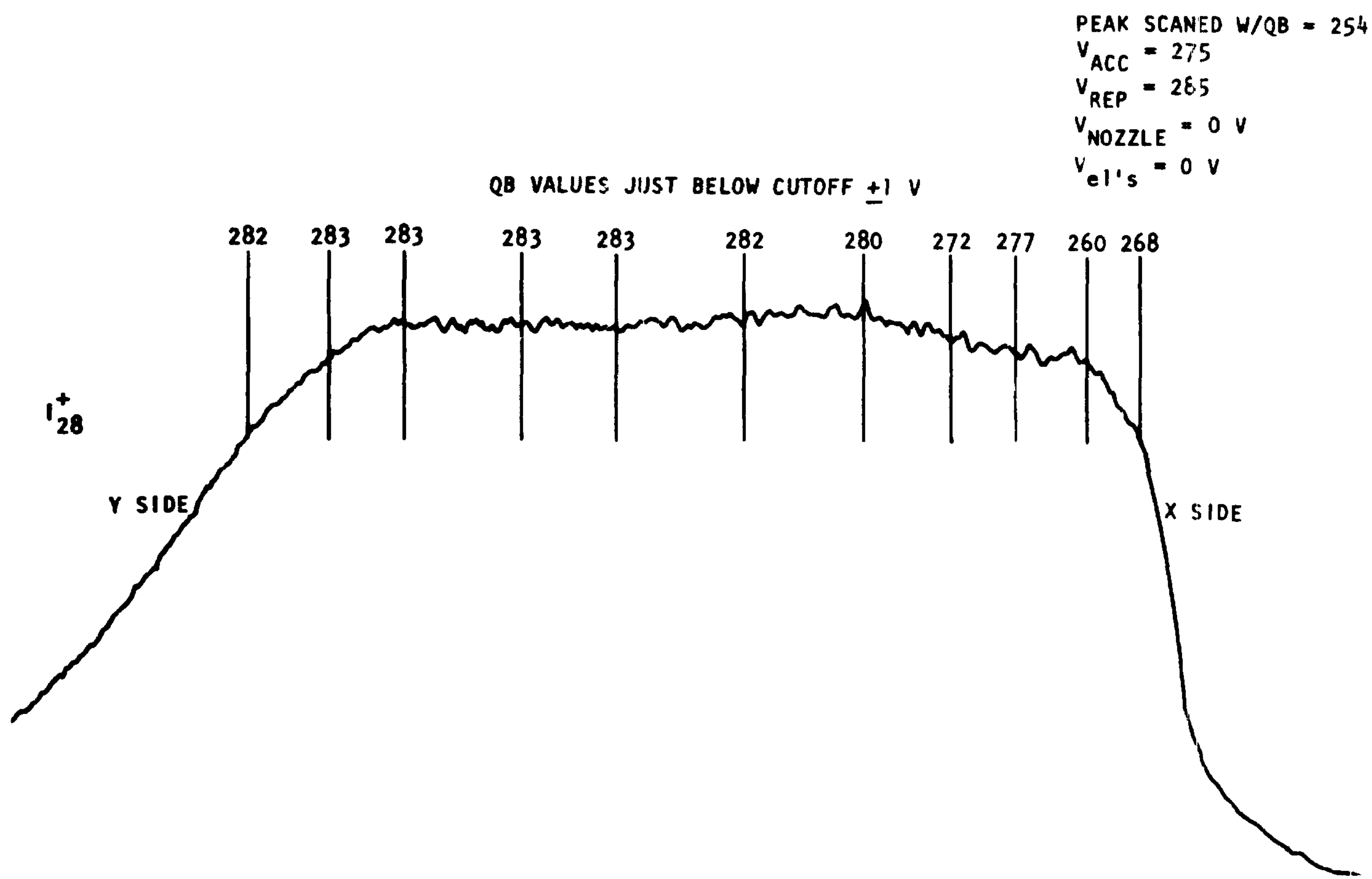


FIGURE 9. QB Cutoff vs Peak Position - Without Mask

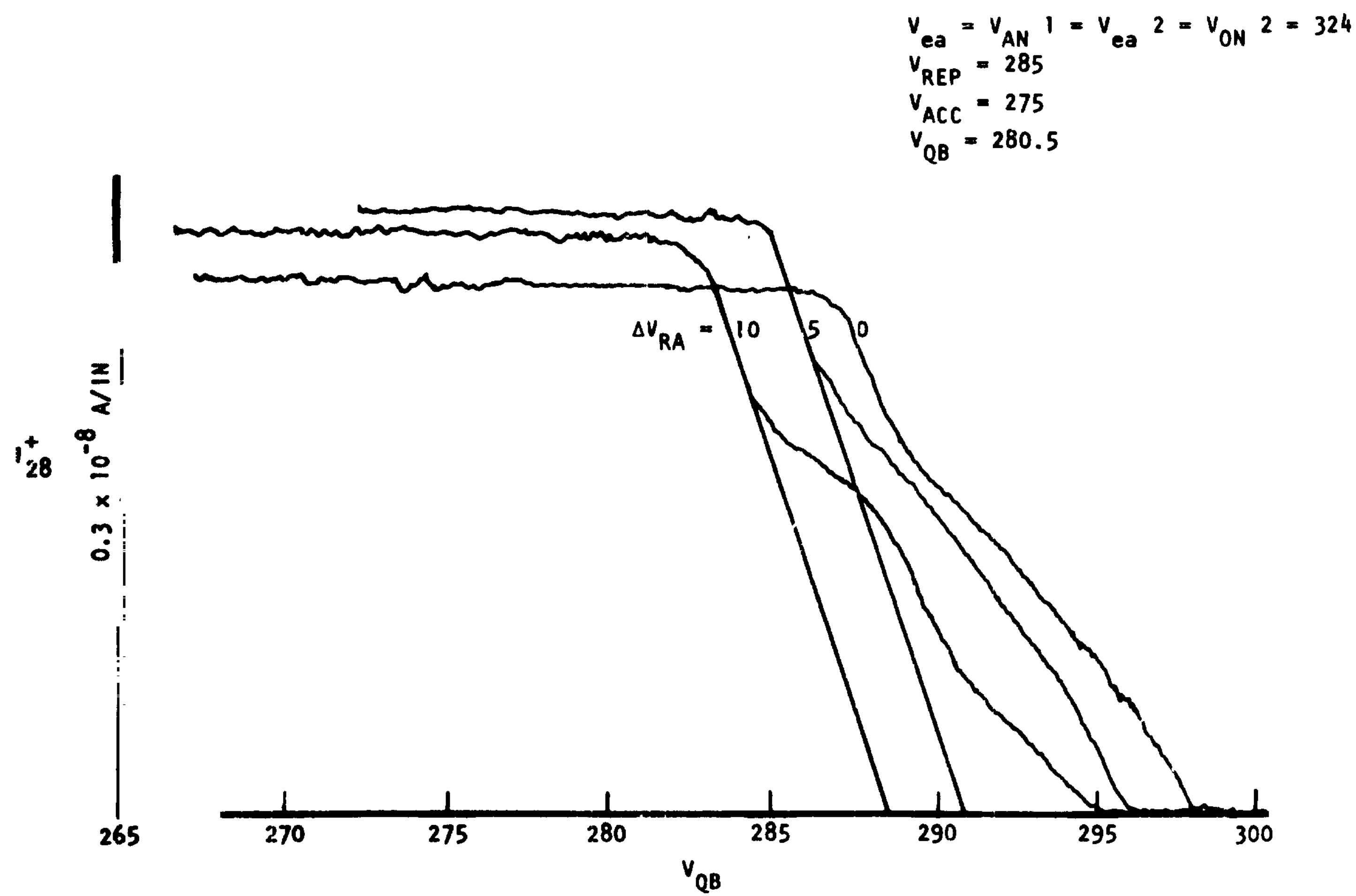


FIGURE 10. Quad Bias Cutoff Runs

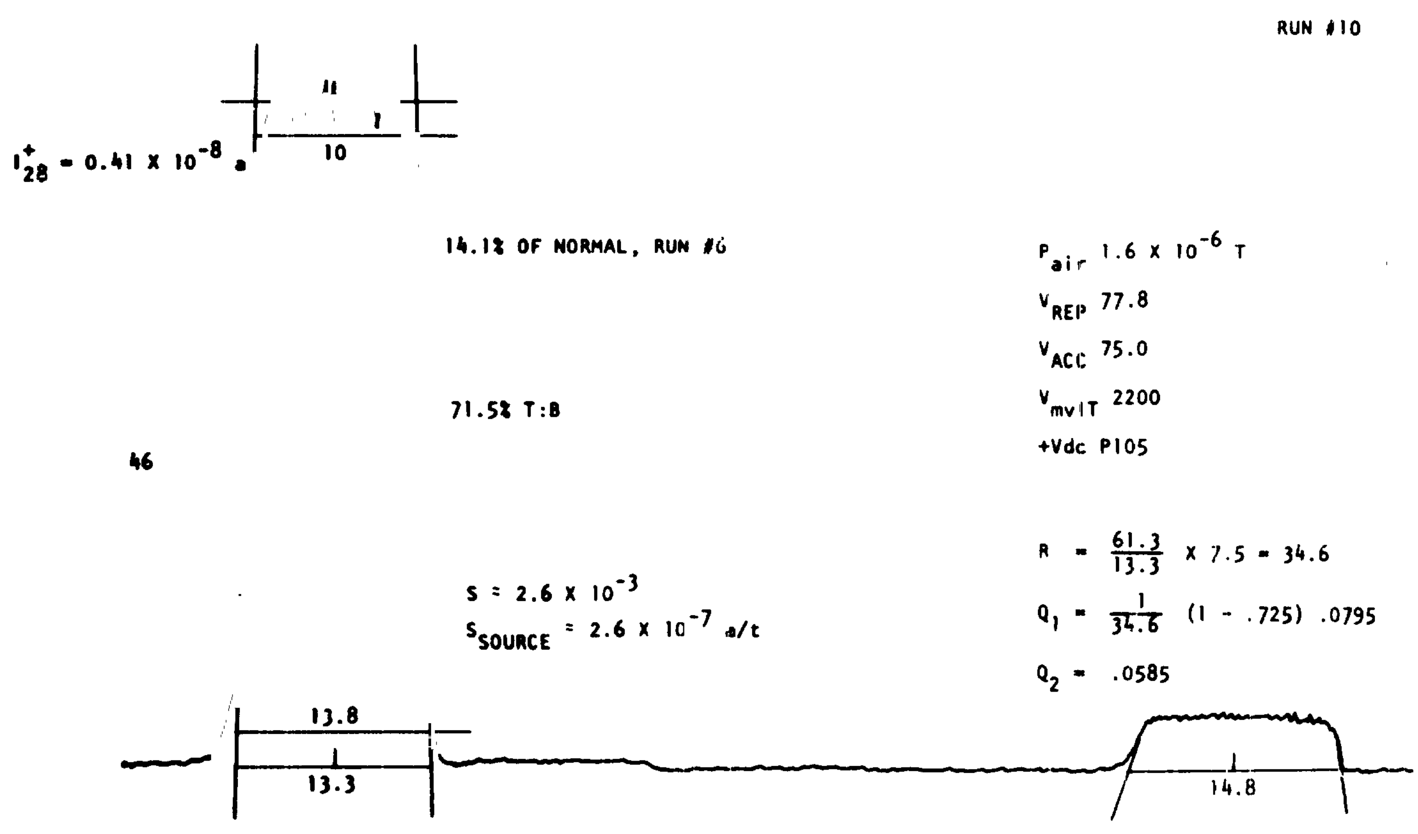


FIGURE 11. Reduced V_{ION} and Proportionally Reduced Δ V_{ION} Test

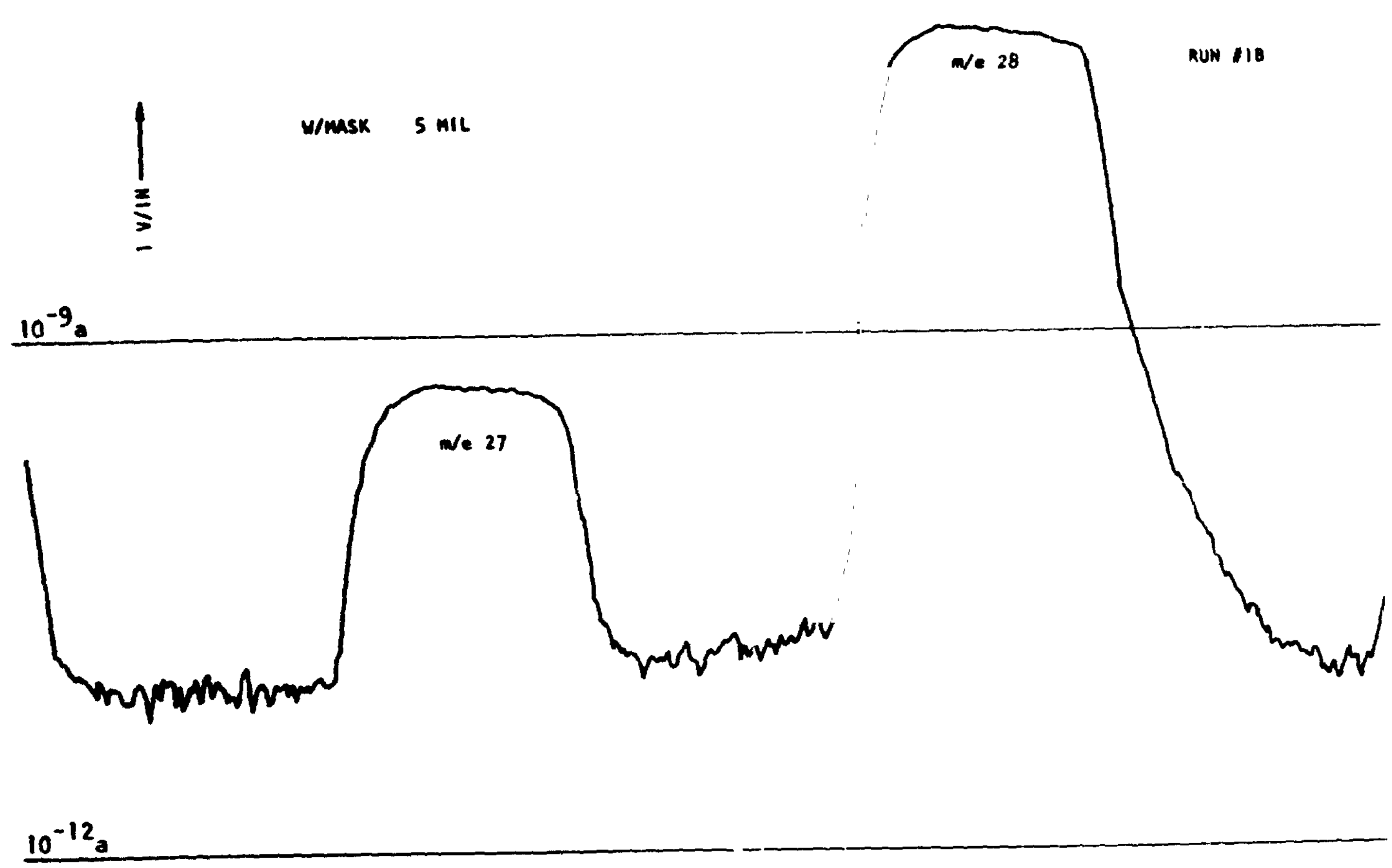


FIGURE 12. Peak Shape with 0.005 Inch Mask on Y-Axis (Lot Output)

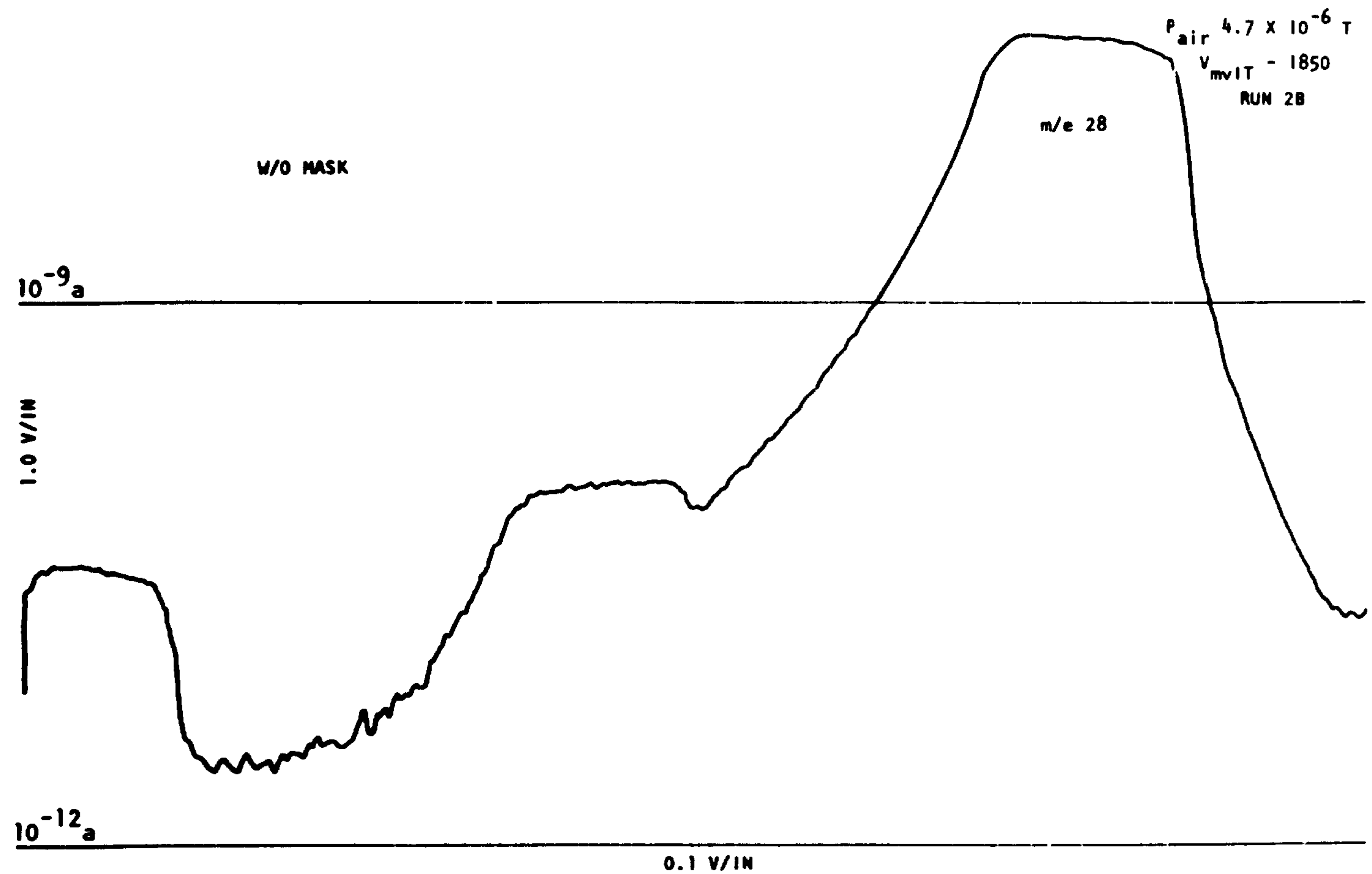


FIGURE 13. Peak Shape Without Mask (Log Output)

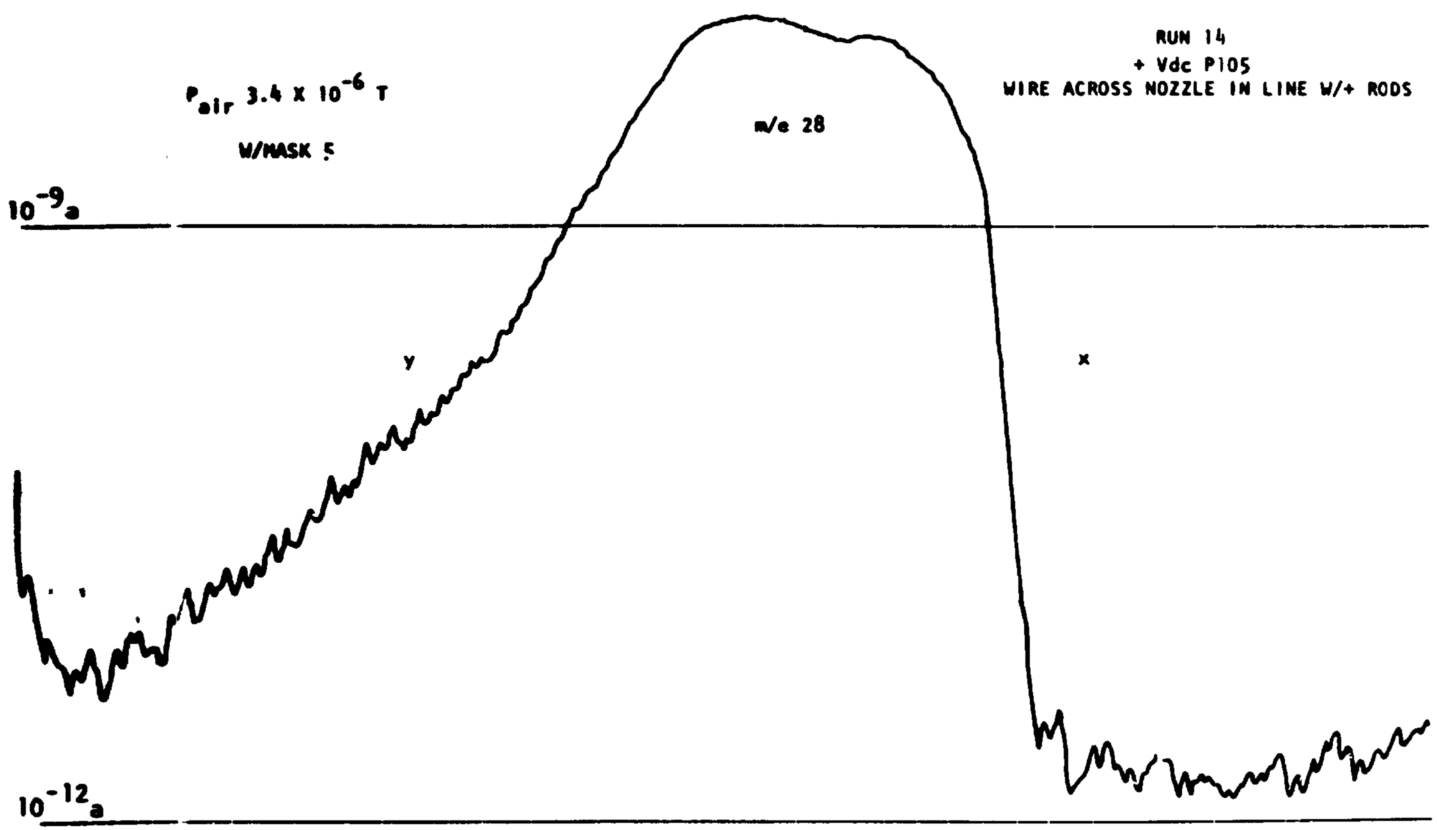


FIGURE 14. Mask on X-Axis (Log Output)

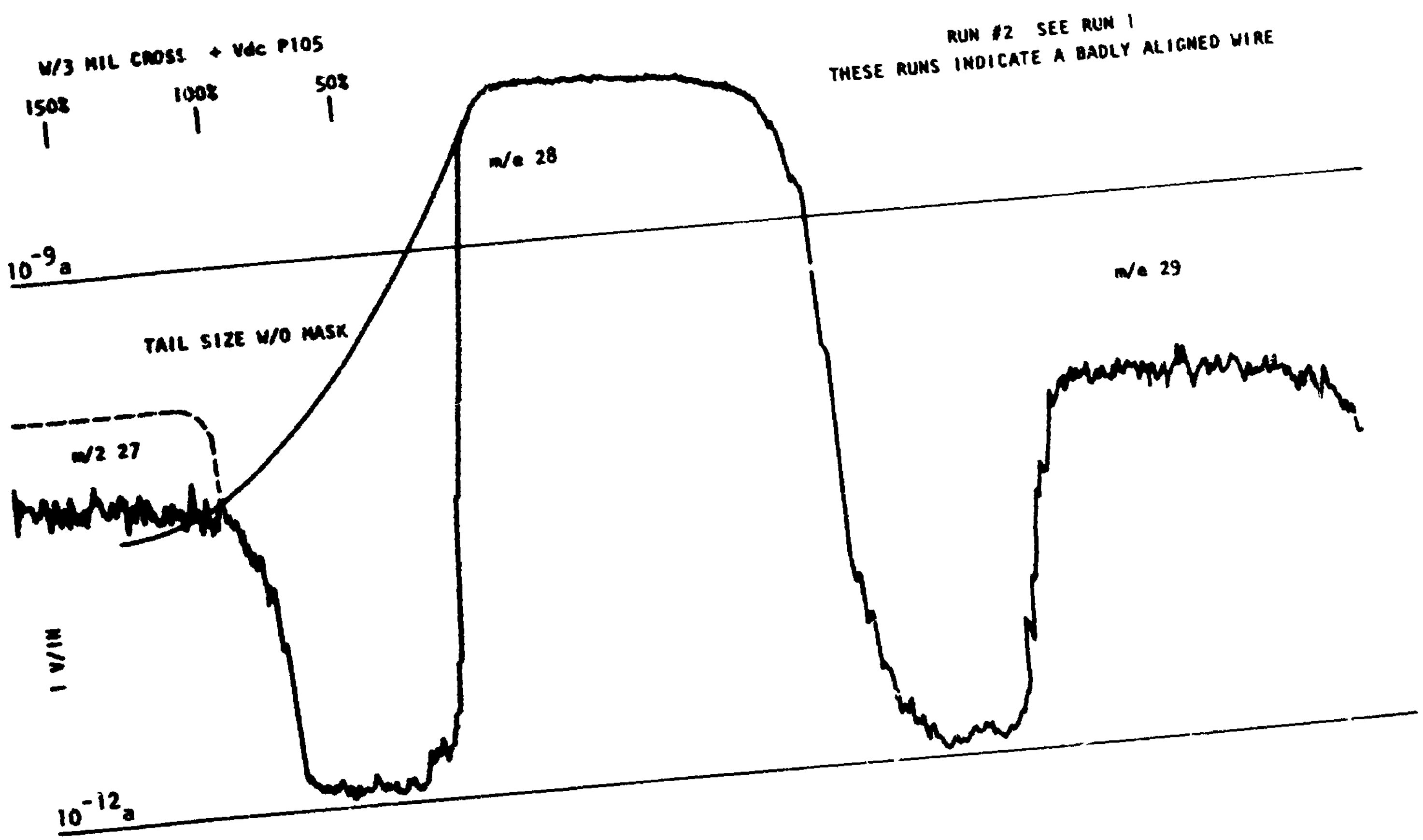


FIGURE 15. Peak Shape With 0.003 Inch Cross (Rod DC Potential Reversed) (Log Output)

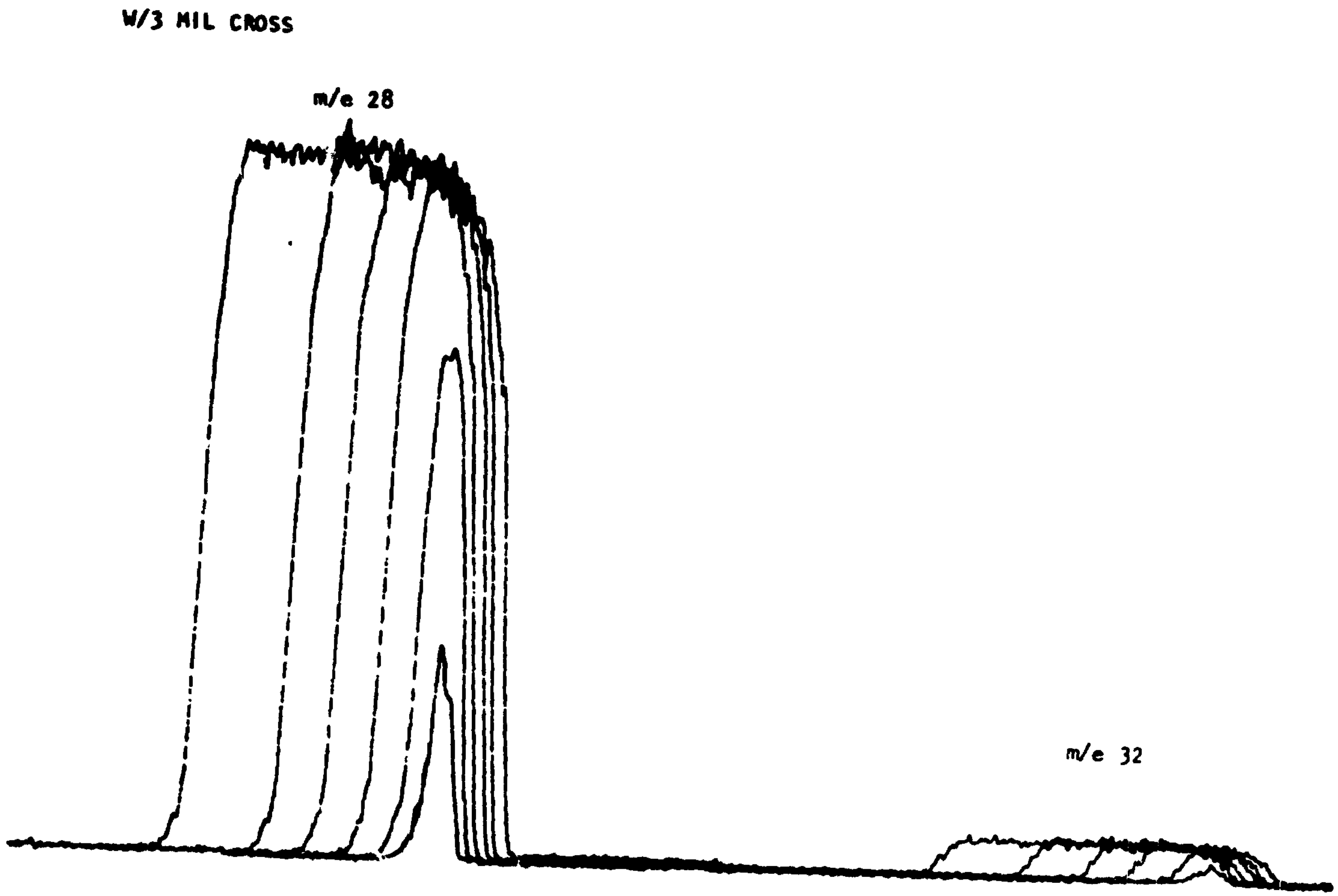


FIGURE 16. Tail Slope vs Resolution

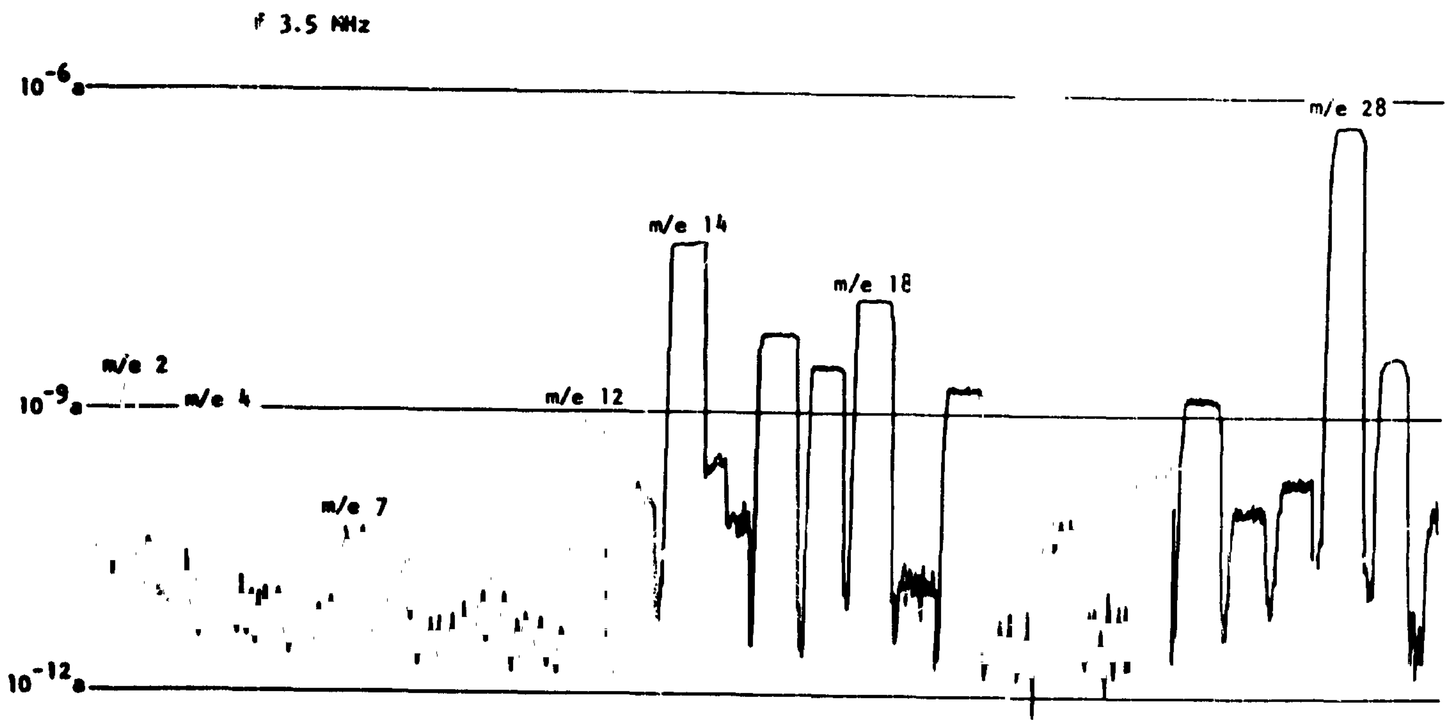


FIGURE 17. Mass Spectrum - m/e 1 to m/e 29 (Log Output)

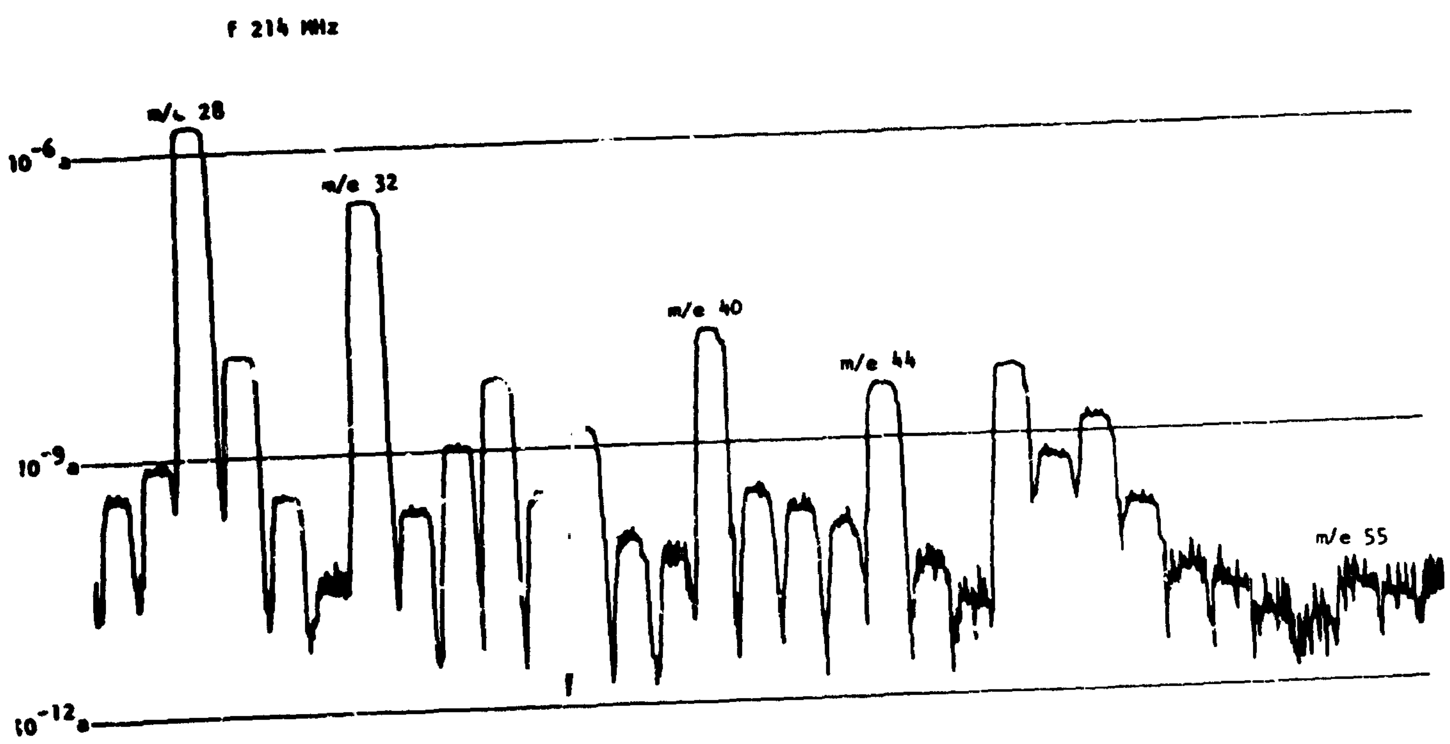


FIGURE 18. Mass Spectrum - m/e 26 to m/e 56 (Log Output)

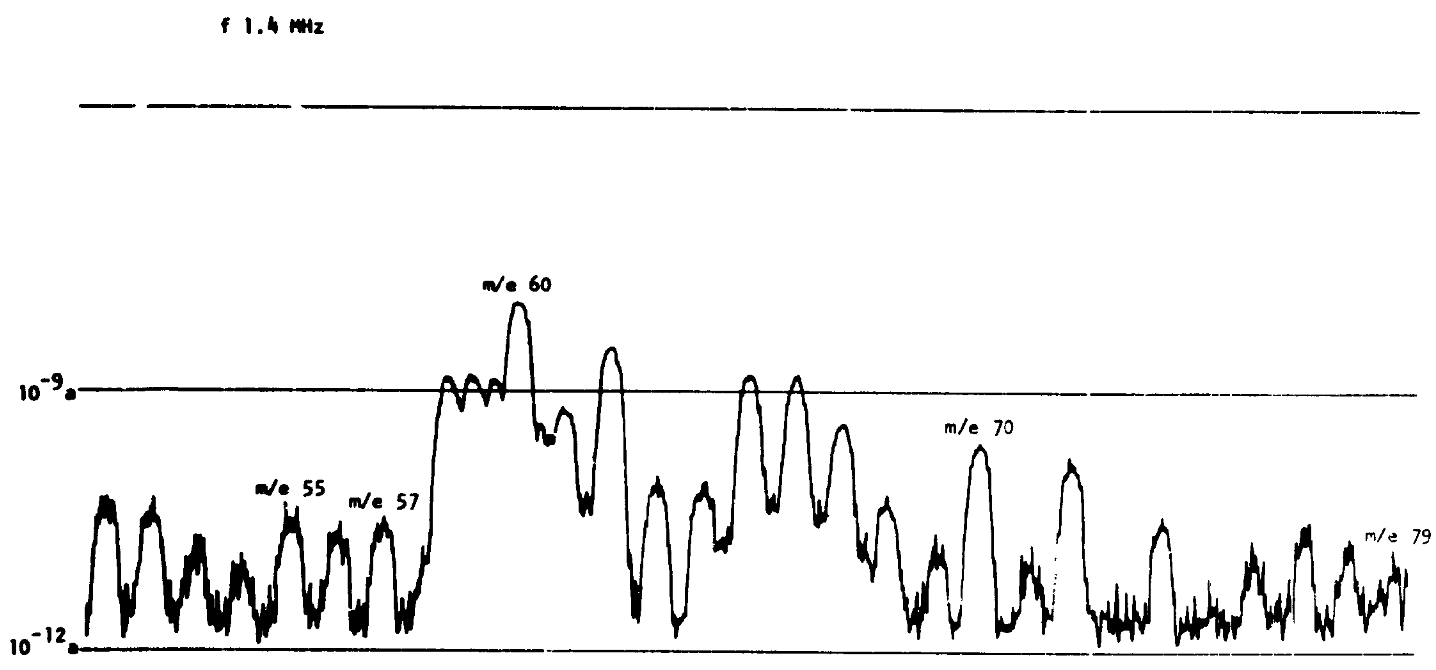


FIGURE 19. Mass Spectrum - m/e 51 to m/e 79 (Log Output)

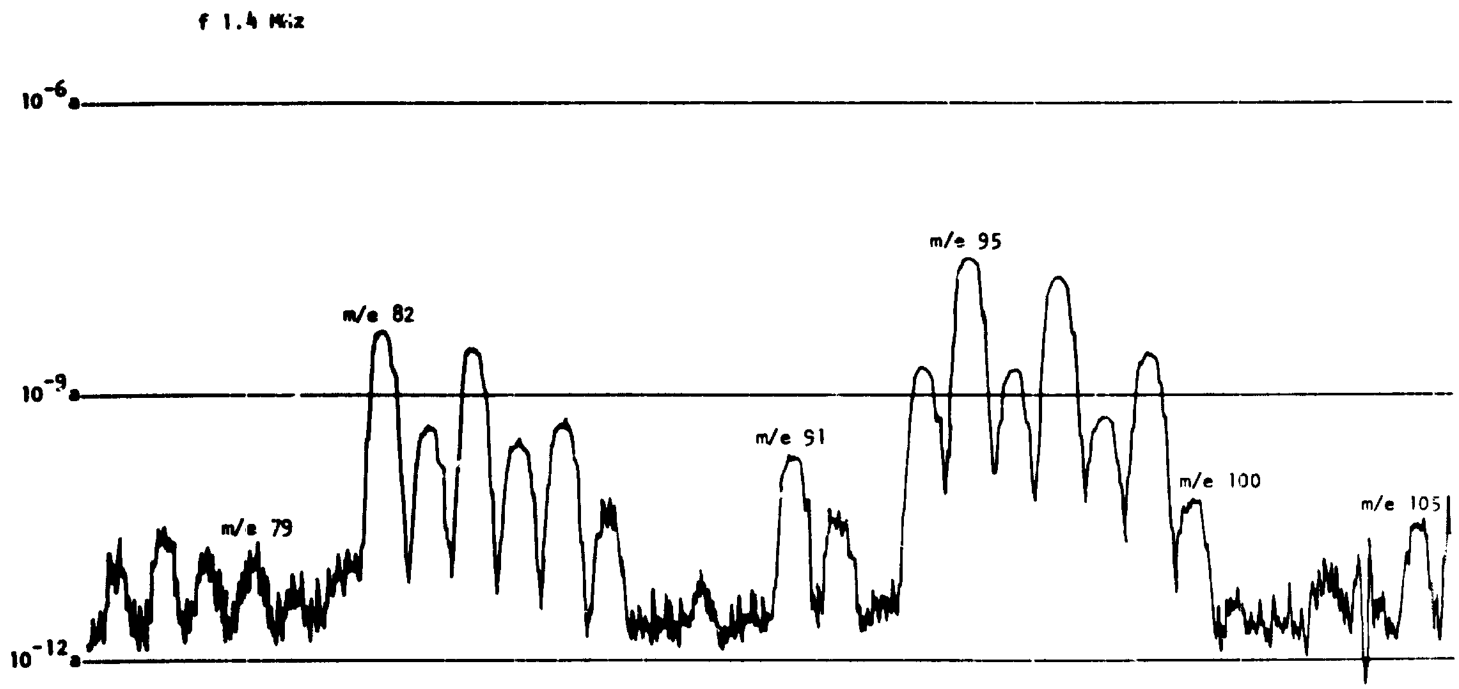


FIGURE 20. Mass Spectrum - m/e 76 to m/e 105 (Log Output)

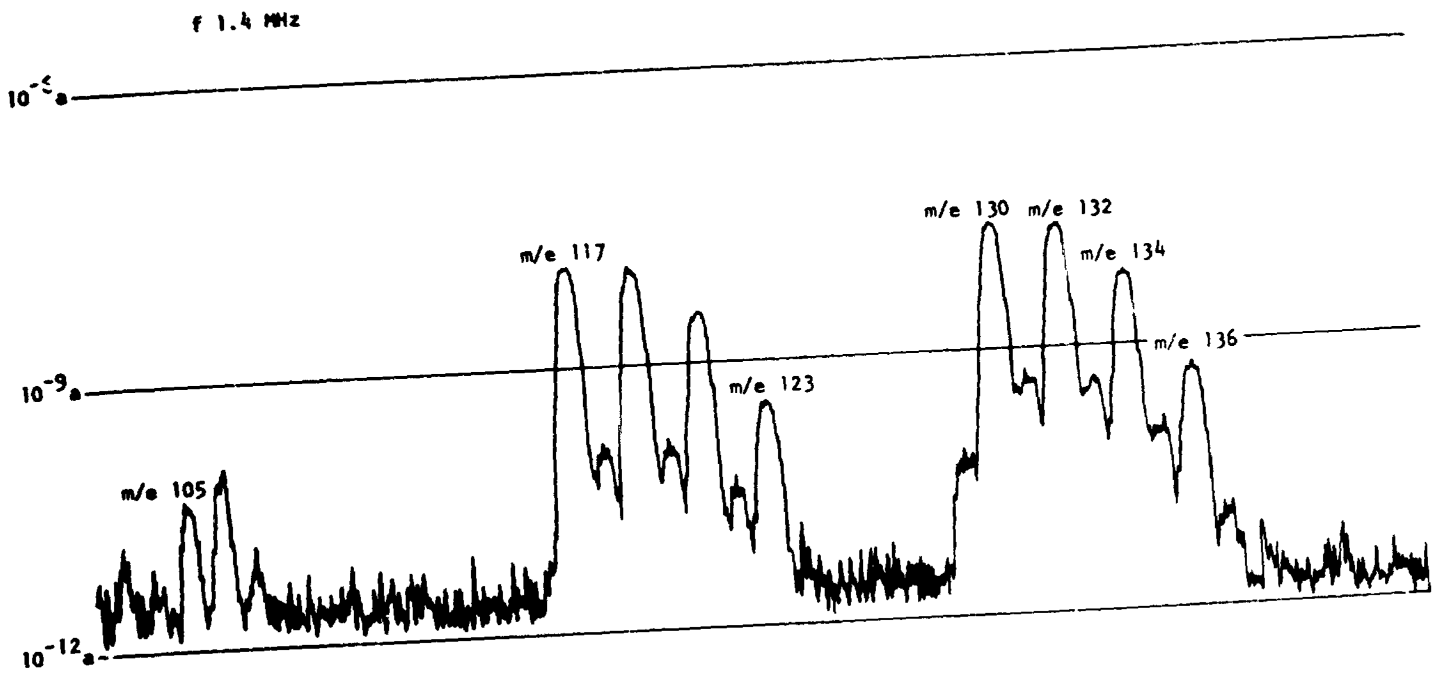


FIGURE 21. Mass Spectrum - m/e 103 to m/e 141 (Log Output)

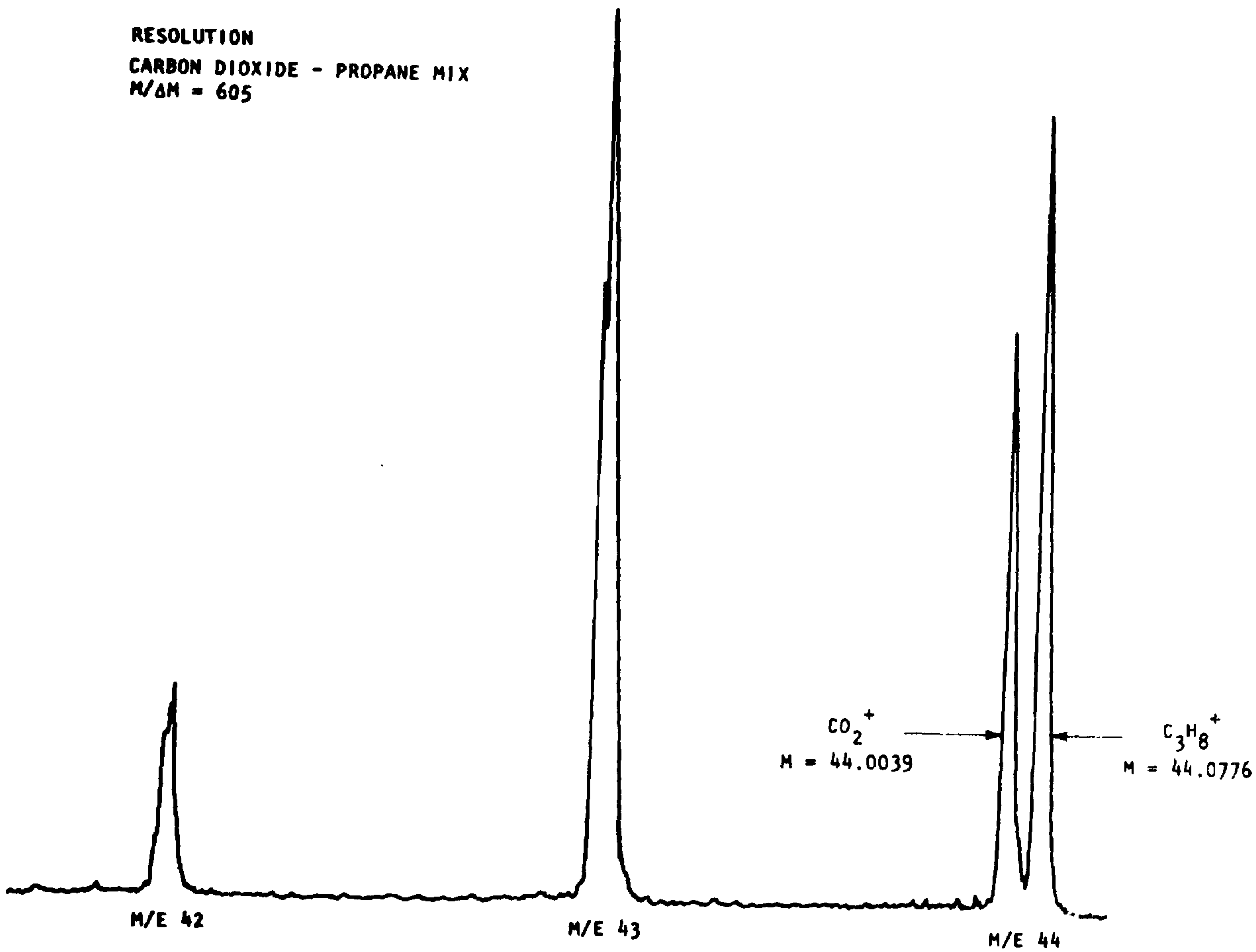


FIGURE 22. Separation of CO_2^+ and $C_3H_8^+$ Peaks

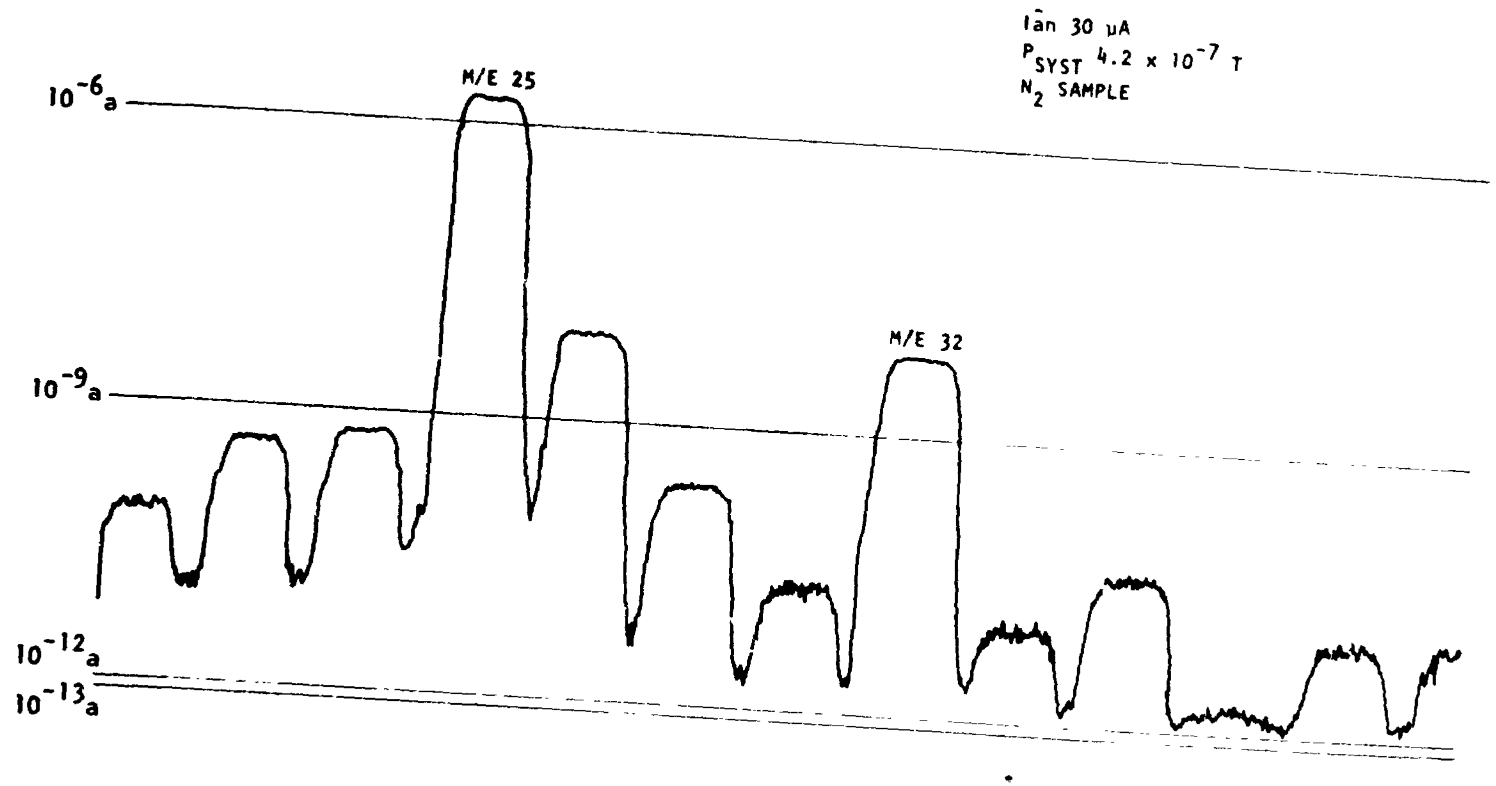


FIGURE 23. Dynamic Range After Weldup (Log Output)

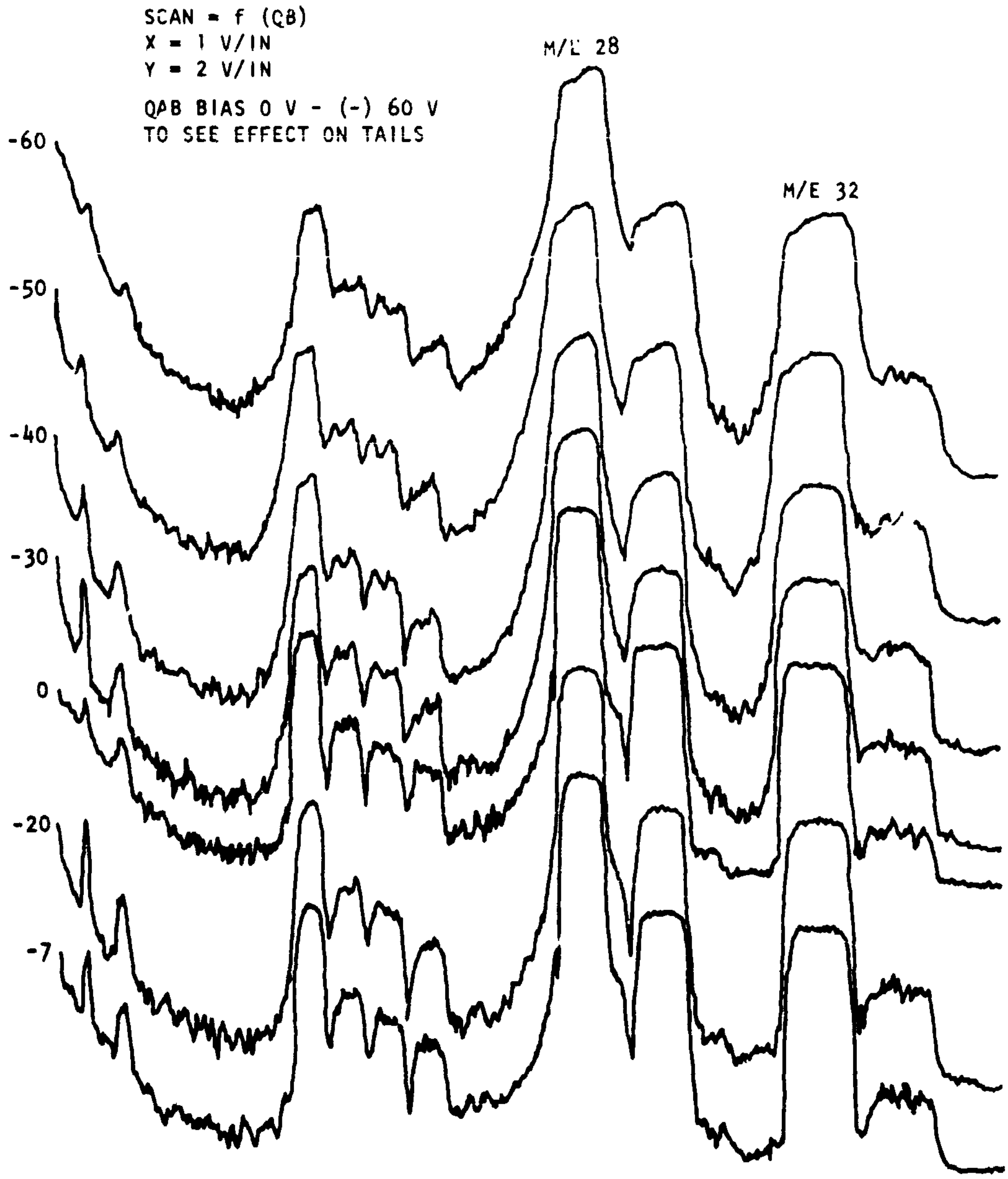


FIGURE 24. Quadrupole Bias Effect on Peak Tails
("Open" Ion Source System)

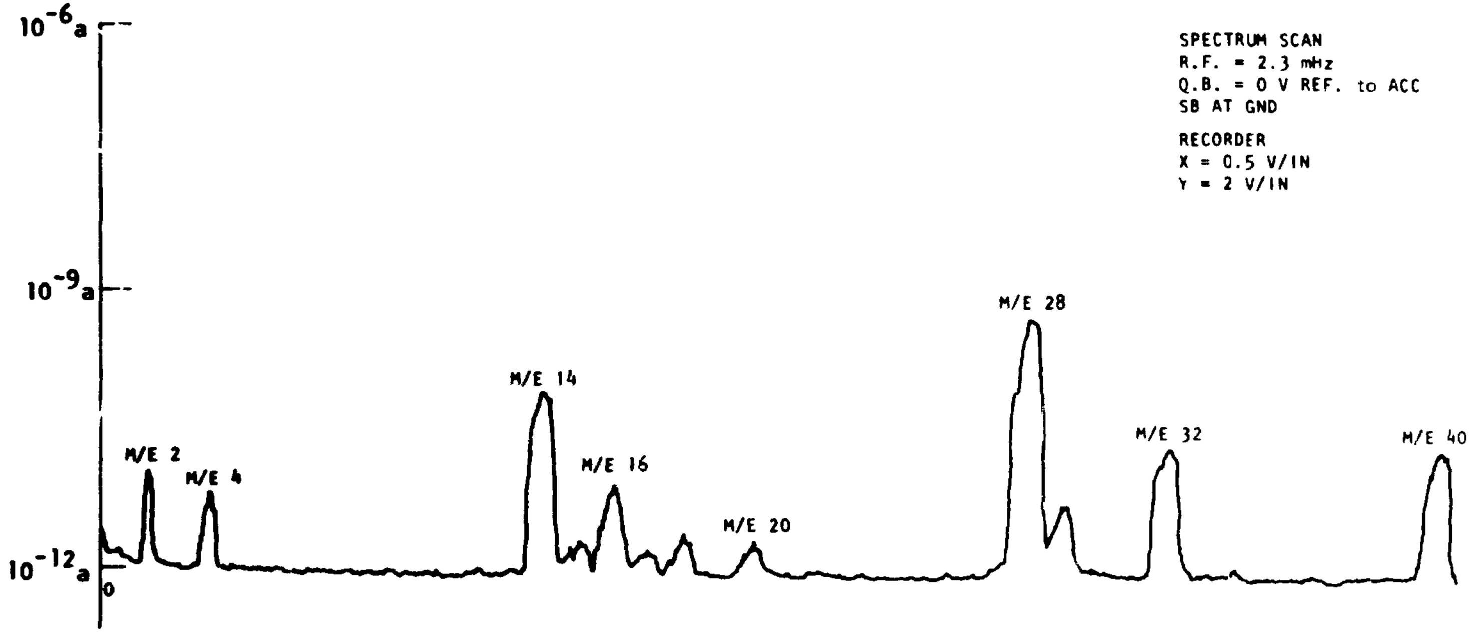


FIGURE 25. Mass Spectrum of Open Ion Source System (Log Output)

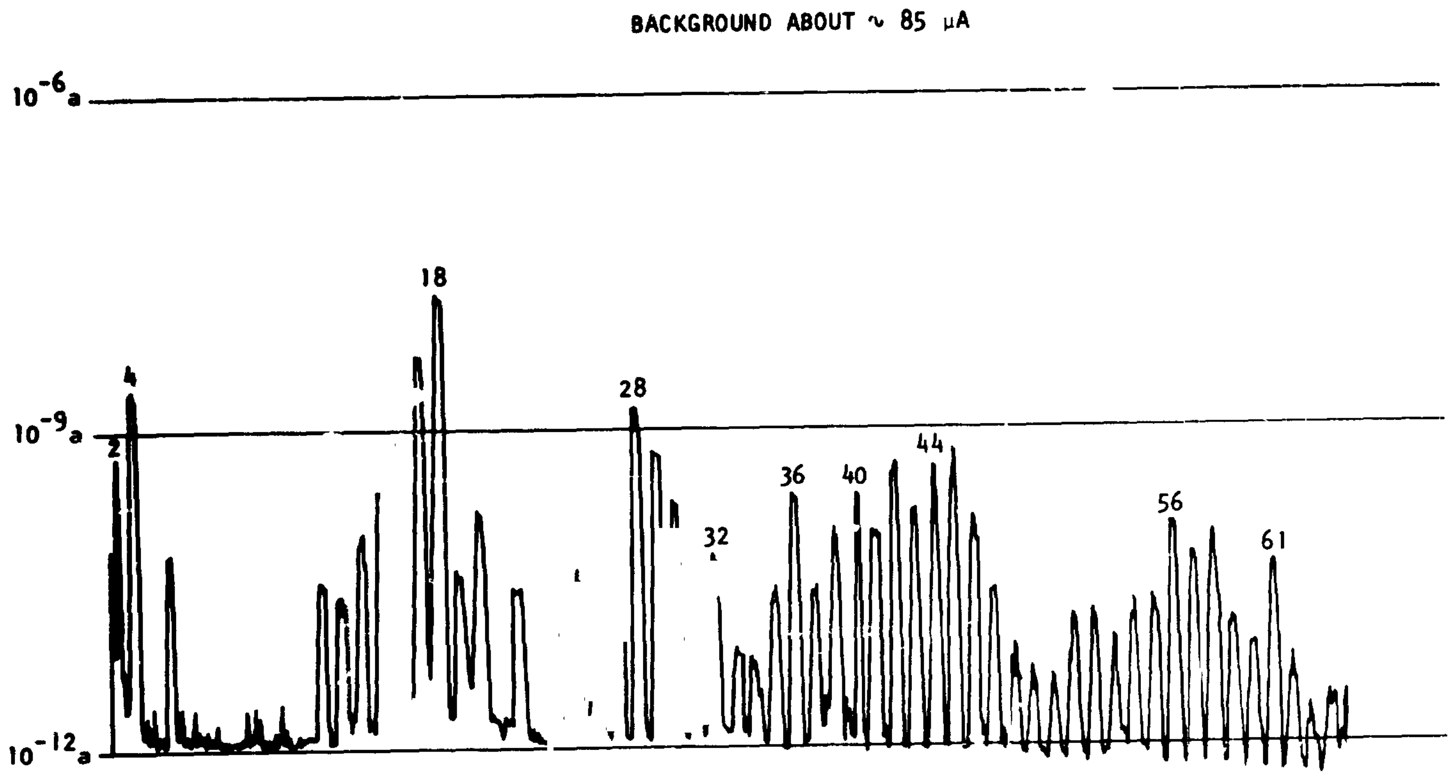


FIGURE 26. Background Spectrum Taken With S/N 001 at ~ 2 x 10^{-7} torr (Log Output)

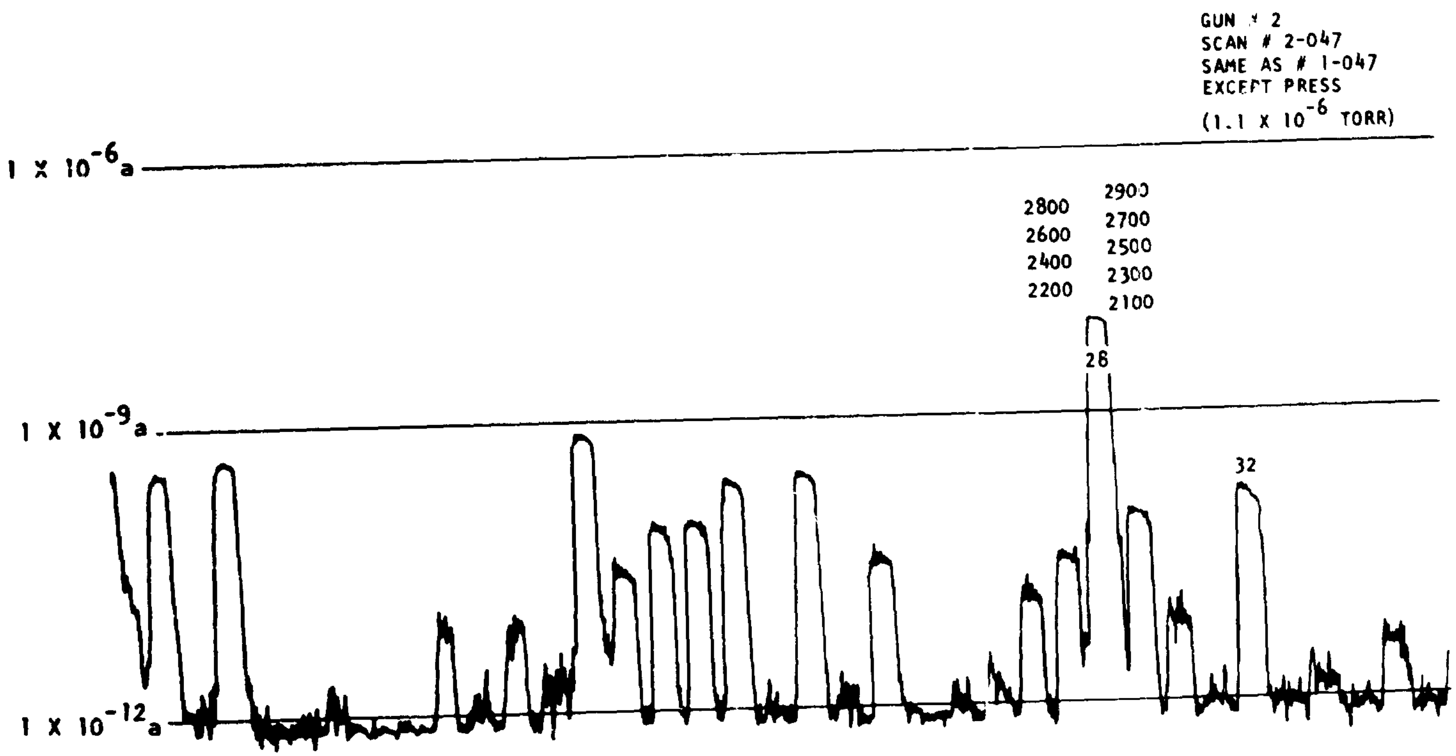


FIGURE 27. Typical Air Spectrum With -2000 Volts on the Electron Multiplier (Log Output)

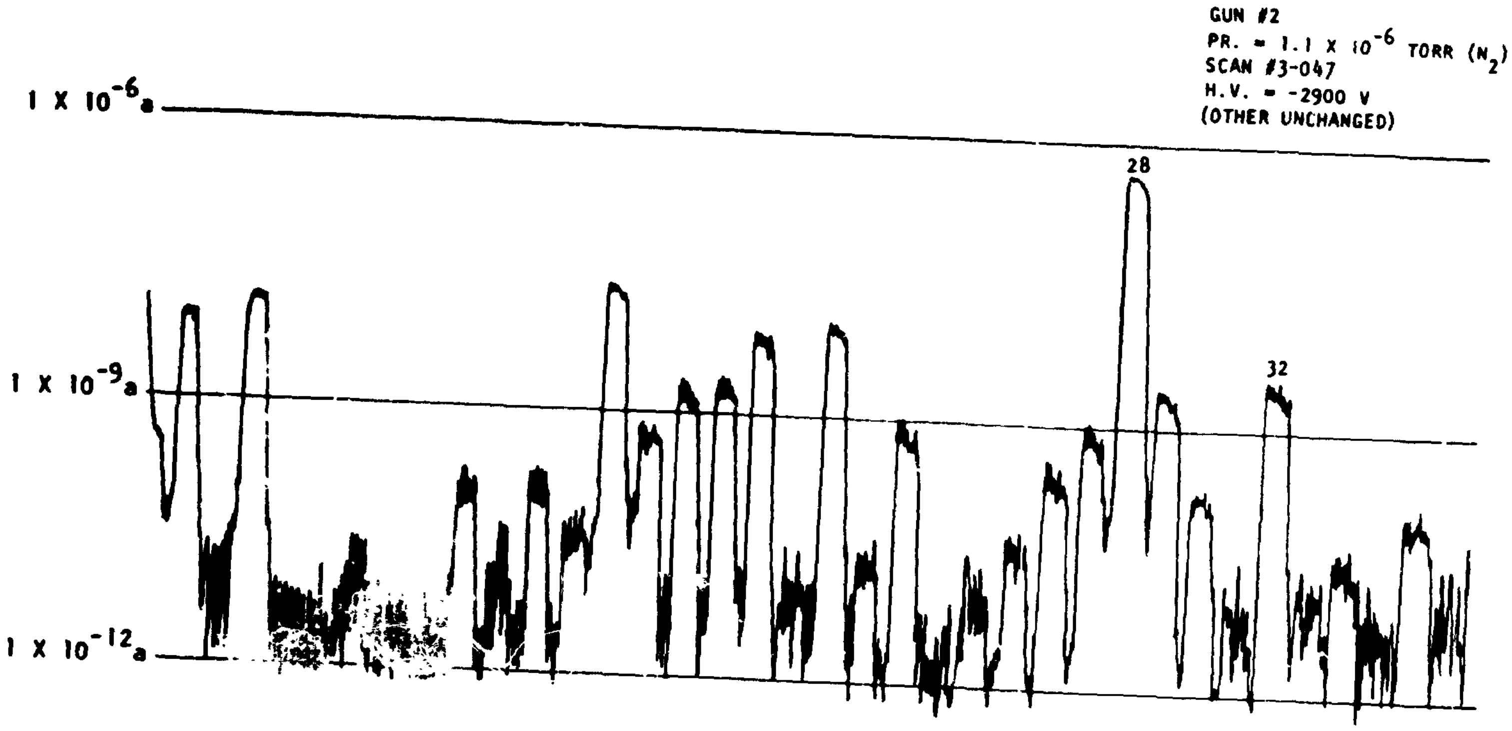


FIGURE 28. Typical Air Spectrum With -2900 Volts on the Electron Multiplier (Log Output)

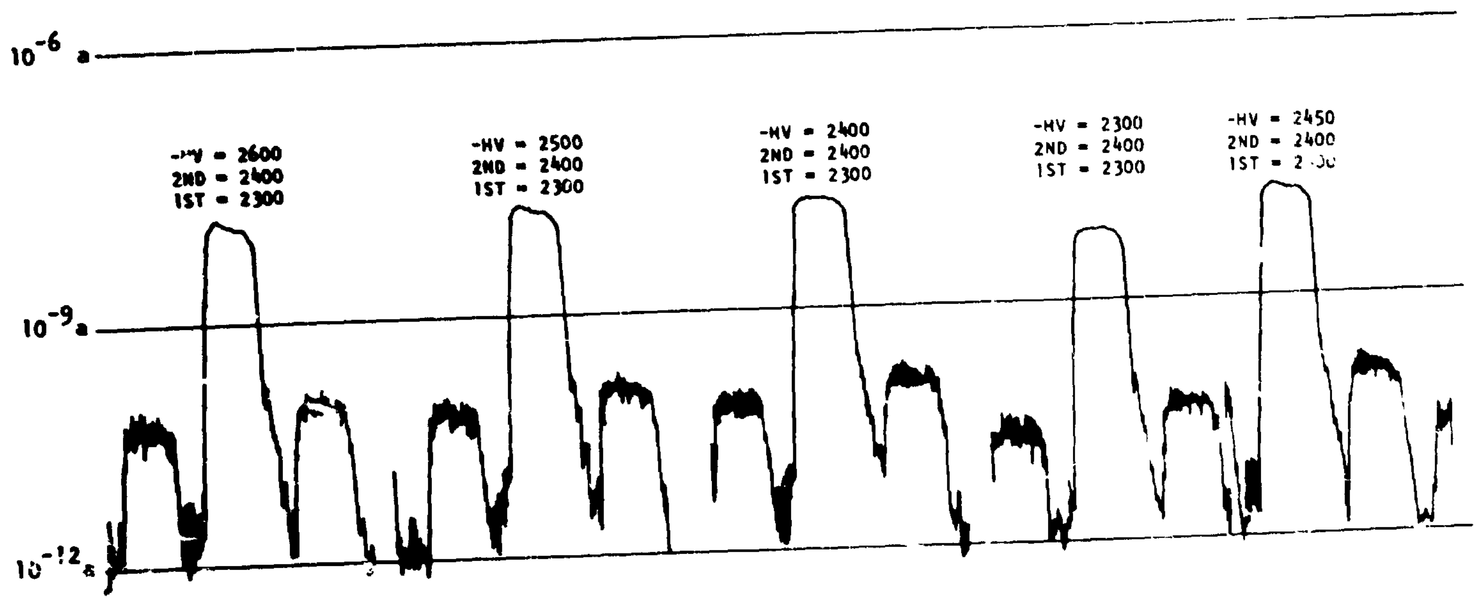


FIGURE 29. Scan No. 4-04J, 2nd Window and -H.V. Voltage Affect Rods Normal (Log Output)

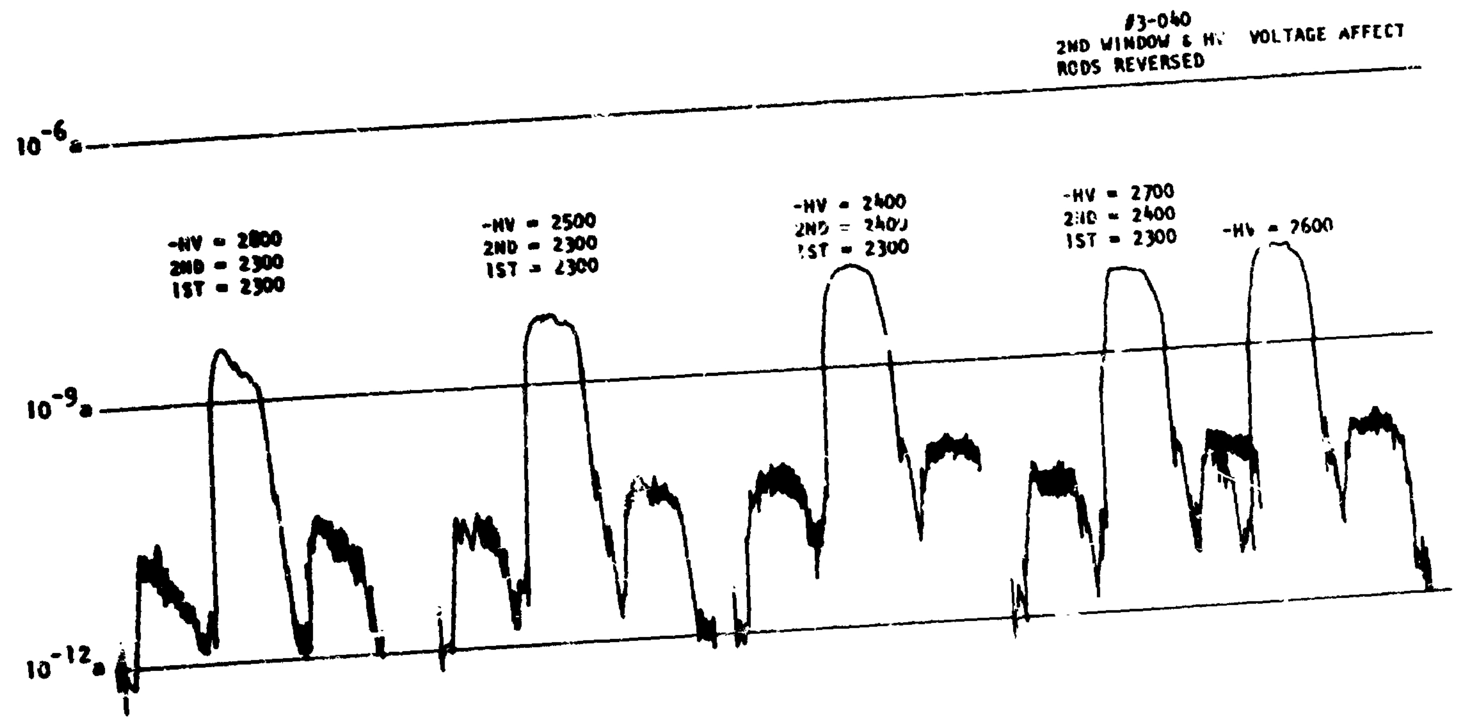


FIGURE 30. Scan No. 3-040, 2nd Window and H.V. Voltage Affect Rods Reversed (Log Output)

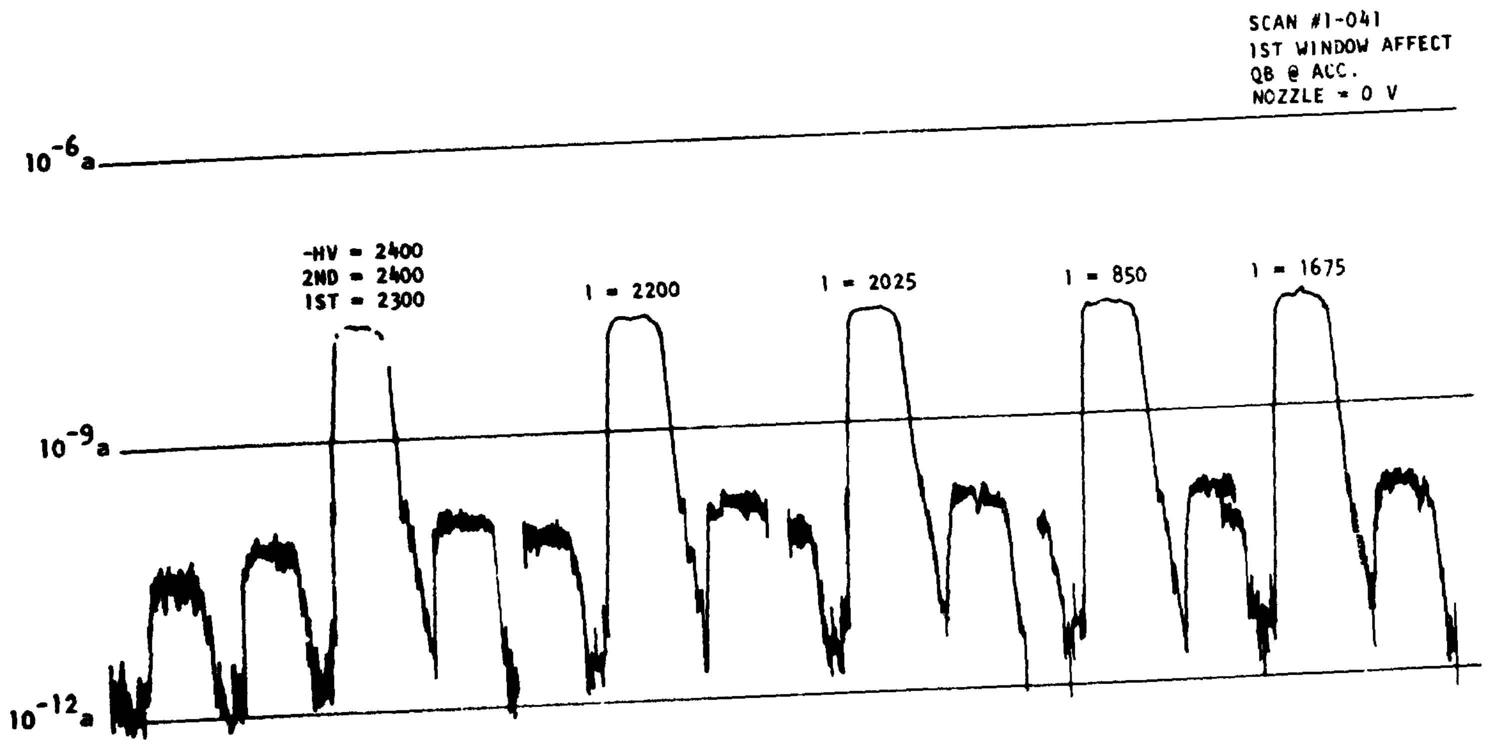


FIGURE 31. Scan No. 1-041, 1st Window Affect QB at ACC. Nozzle = 0 V (Log Output)

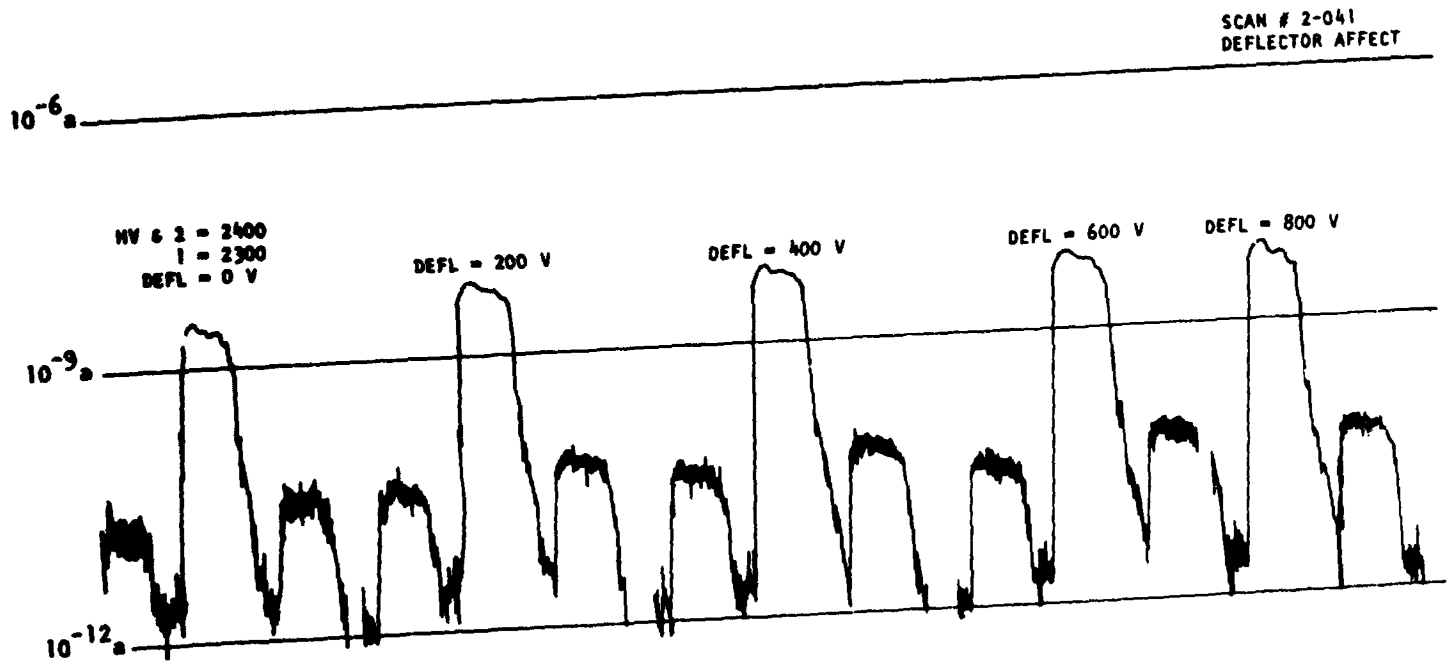


FIGURE 32. Scan No. 2-041, Deflector Affect (Log Output)

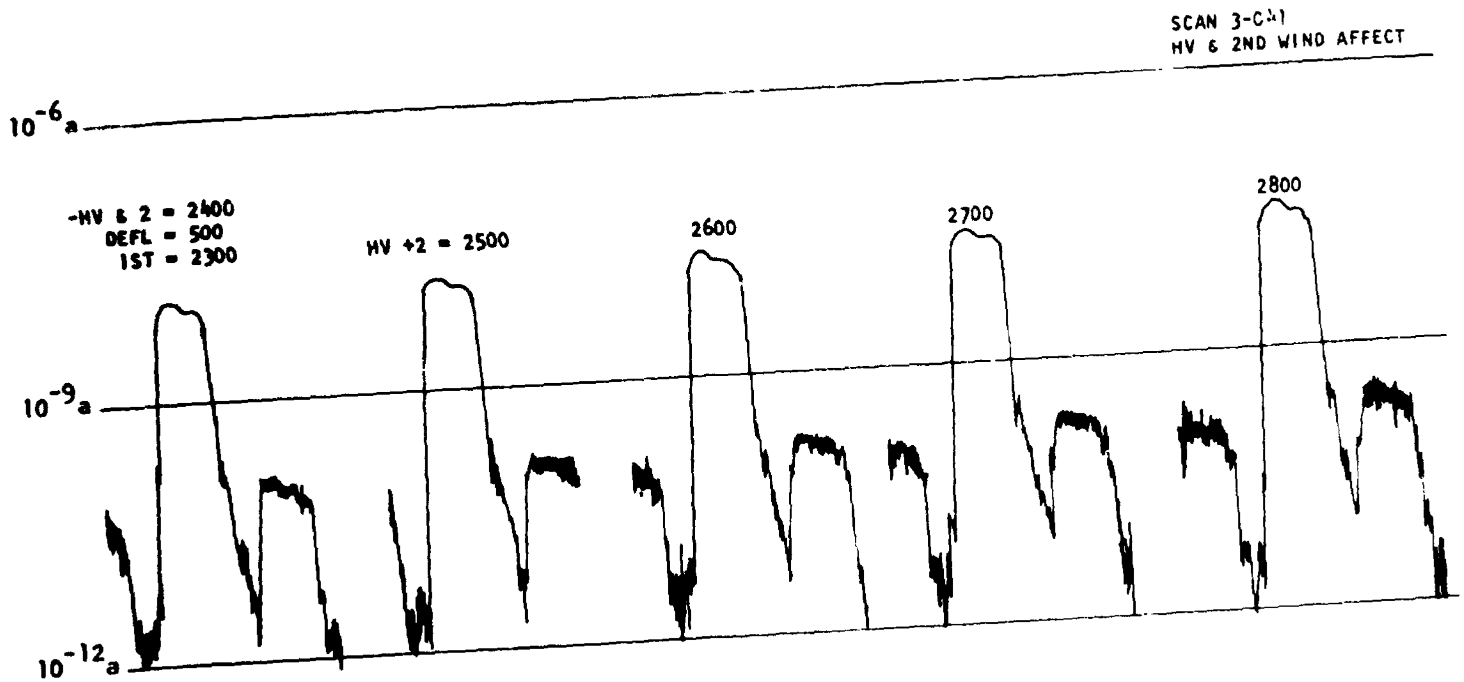


FIGURE 33. Scan 3-041, H.V. and 2nd Wind Affect (Log Output)

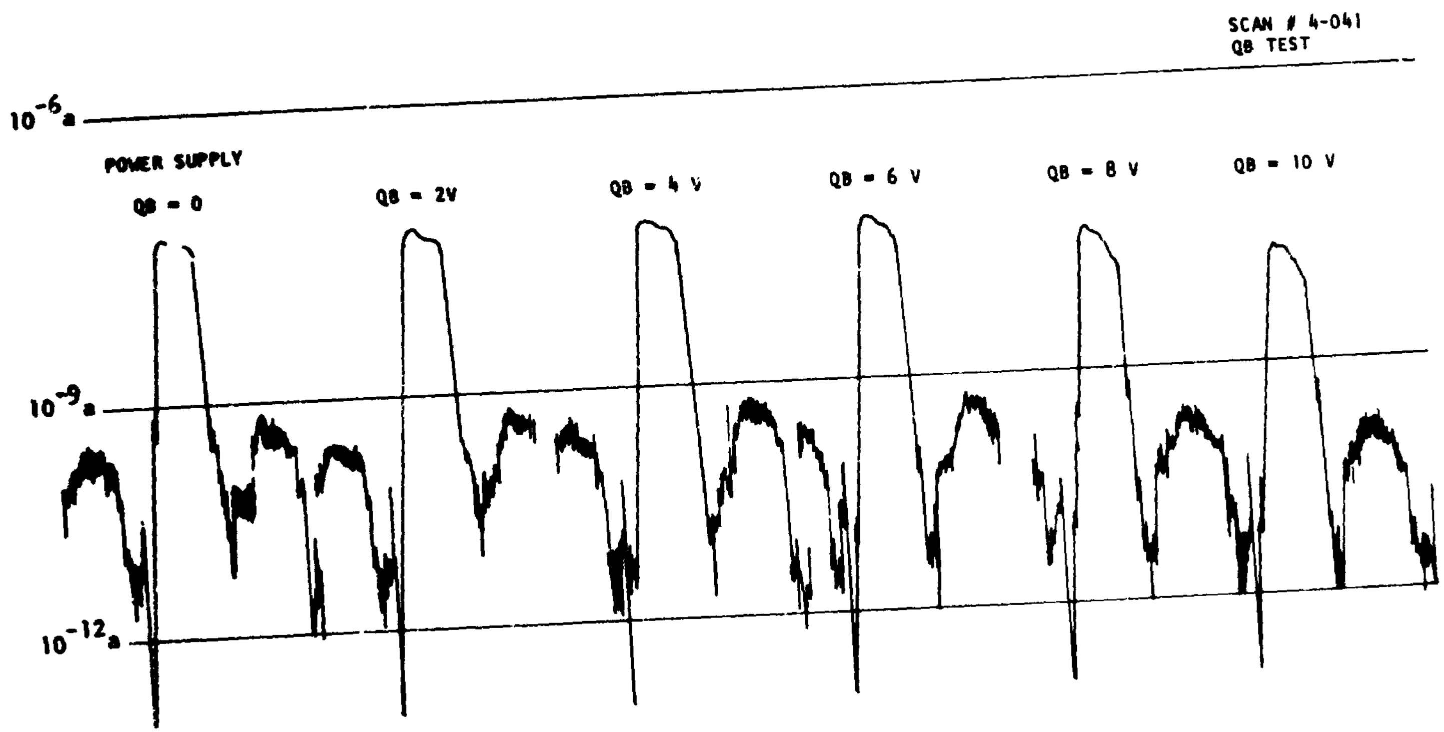


FIGURE 34. Scan No. 4-041, QB Test (Log Output)

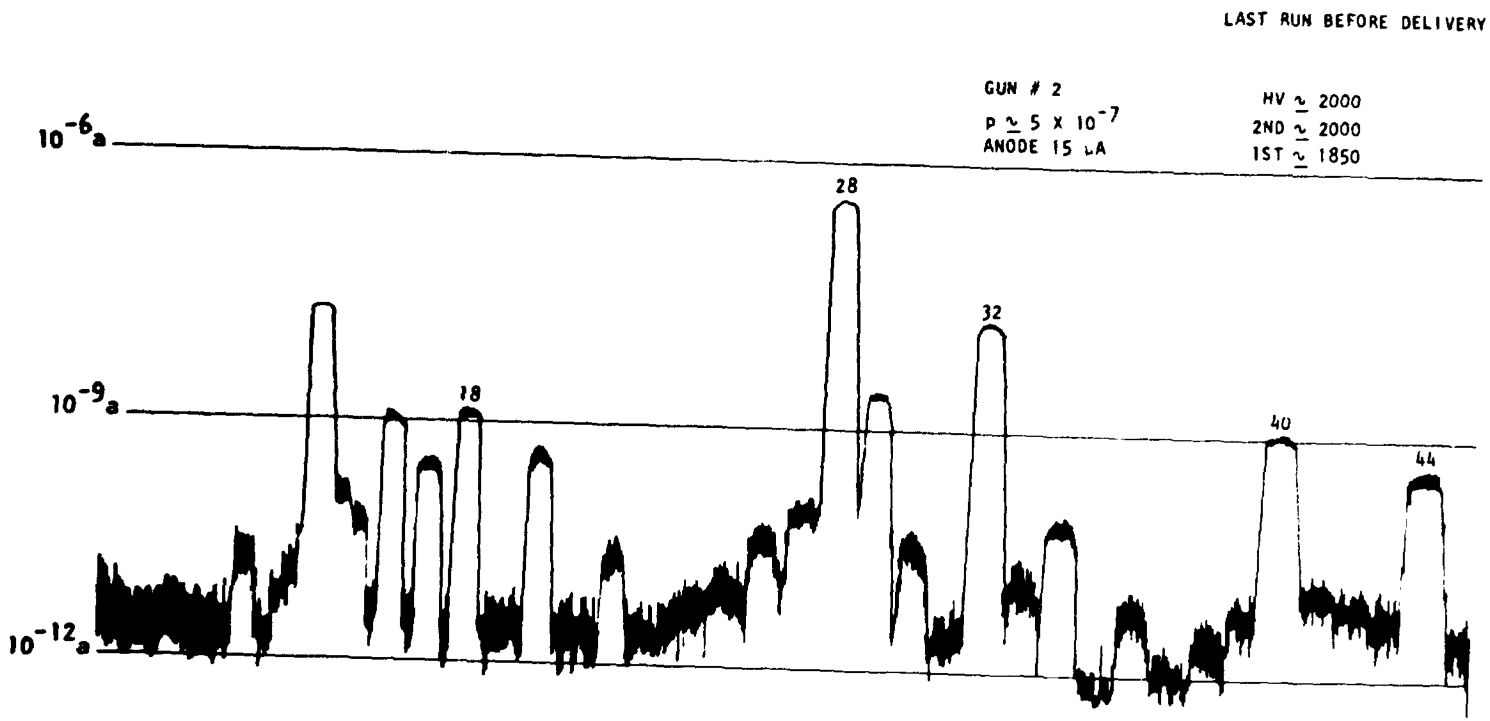


FIGURE 35. Last Run Before Delivery (Log Output)